Decision Making for Knowledge Management in the Tequila Sector: A Fuzzy Logic Model

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Abstract: Knowledge management creates value for organizations, allowing them to be more innovative, productive, and competitive if that knowledge is used appropriately. Through this management, vital information is created and disseminated systematically and efficiently, and at the same time, knowledge learning is adopted, transformed, shared, and applied. This research analyzes decision-making for knowledge management in a mature low-tech sector, such as Tequila in Mexico. At the same time, it generates a predictive model of knowledge management that allows innovation in this sector by combining knowledge of modern technologies and ancestral knowledge in manufacturing the product, along with providing support to public policymakers and decision-makers to support small producers and rural communities. The methodological strategy used is an expert system through fuzzy logic, starting from a data set based on the patterns found in a Bayes network. The results show that the most relevant variables in decision-making for knowledge management in the Tequila sector are modern technologies, ancestral knowledge, and the Denomination of Origin. Under the above, it could be inferred that the ancestral knowledge variable is the most influential in achieving high values in managing knowledge management -the output variable preserving the value of a product with a designation of origin.

Keywords: Bayes network,Decision making, Knowledge management, Fuzzy logic model, Machine learning, Tequila sector, México, Low tech

1. Introduction

Knowledge management is a strategic element in the innovation and competitiveness of organizations, for which learning capacity is a critical factor in achieving it. The agribusiness sector is no exception; they must implement knowledge management practices to achieve this. That sector is characterized by small family businesses with a low propensity to generate knowledge and innovation (Vesperi et al., 2021).

According to Gaziulusoy et al. (2013), Pelizza (2020), and Vesperi et al. (2021), agribusiness, being traditional and low-tech companies, are in a situation in which they need to find and implement new ways of innovation, to create, provide and generate value to face current challenges and be more competitive. However, this sector cannot generate new knowledge independently; therefore, it must go beyond its limits (Gaziulusoy et al., 2013; Pelizza, 2020). In this way, knowledge is acquired through or in conjunction with various actors (Chesbrough, 2006) with which they are linked. According to the above, agribusinesses would benefit from the exchange of knowledge with partners, research centers, and universities (Vesperí et al., 2021),

The Tequila sector in Mexico is a traditional and low-tech agribusiness in which knowledge management is crucial to innovation and competitive advantages. That sector has established itself as one of the main agro-industries in Mexico by producing one of the most emblematic alcoholic beverages worldwide and with the denomination of origin (Macías, 2001; Gallardo, 2019; Terán-Bustamante et al., 2022). Currently, this industry represents today more than 25,000 producers in 5 States, and 181 municipalities, a production of more than 2,611 thousand tons of agave that represents 651.4 million liters per year (CRT, 2023); 292 companies certified with Denomination of Origin (CRT, 2023), 1,831 registered trademarks (1,582 national and 376 abroad) (CRT, 2023), employment for more than 70 thousand families (IIEG, 2022).

According to the above, the Tequila industry represents a tremendous economic value for Mexico while having the potential to contribute to rural development and small producers. However, this sector has not benefited the local population or the environment of the drink’s origin region. Four factors are argued to explain poor performance: performance:

- The power of the large Tequila-producing companies and the pressure exerted by transnational companies to recognize the contributions of the region of origin and small agave growers (Bowen, 2012; Terán-Bustamante et al., 2022).

- Availability and supply of raw materials suffer from cyclical crises that fluctuate over the years and considerably affect both production levels and costs (Herrera et al., 2018; Terán-Bustamante et al., 2022).
- Connection with the land of origin – geographical indicator (Bowen, 2012) and ancestral knowledge (Terán-Bustamante et al., 2022).
- Management of ancestral knowledge with modern technologies that preserve the benefits of the Denomination of Origin (DO) and explore the knowledge for the natural conservation of the Agaváceas and Nolináceas (Golubov, 2007) for the sustainability of this sector.

Therefore, it is necessary to create an environment that favors disseminating knowledge among companies, communities, producers, and other organizations such as universities and research centers to use knowledge as a strategic resource (Núñez, 2015).

In general, knowledge in organizations needs a structure that facilitates its use effectively. On the other hand, the knowledge generated and appropriated through innovation processes, the acquisition of technology, work with suppliers and customers, interactions with competitors, and the business environment present difficulties to be integrated into the daily actions and activities of the organization. For this reason, it is necessary to develop mechanisms that allow all people to have the full potential of knowledge dispersed in the organization.

Derived from the previous problem, the questions that guide the present research are, What are the critical factors for adequate decision-making in the Tequila Industry in Mexico for optimal knowledge management? Using a knowledge management model, how can the tequila sector make better decisions that benefit all producers and rural communities?

This paper aims to provide knowledge to decision-makers in the public and private sectors to funnel public policies that support rural communities and smallholders. At the same time, generate knowledge by providing a knowledge management model in a low-tech industry such as Tequila, where innovation is developed.

The present work is organized into three sections. The first section addresses the theoretical framework, the main concepts of scientific knowledge, ancestral knowledge, and knowledge management and its relationship with innovation. A very brief characterization of the Tequila sector in Mexico is also made. The second section presents the analysis methodology and model construction based on Bayesian Networks (BNs). The methodological strategy used is an expert system through fuzzy logic, starting from a set of data based on the patterns found in a Bayes network. Finally, the third section presents the results, discussion, and conclusions.

2. Theoretical Framework

2.1 Knowledge Management: Conceptualization and Importance

Knowledge management aims to generate, share, and use explicit (codified) knowledge and know-how existing in a given space to respond to the needs of individuals and communities in their development (ILO, 2023).

Therefore, knowledge management has become the primary key to creating value, so knowledge has been considered a strategic source in organizations.

Value creation is mainly related to activities that concern the human capital of the company, which are aimed at creating new skills through research, learning, or knowledge acquisition. This generation of new knowledge must be linked to its conversion into innovations that provide commercial value (Solleiro and Castañón, 2004 and 2016; Terán-Bustamante et al., 2022).

That involves creating and deploying knowledge management strategies that integrate five fundamental actions: understanding knowledge needs and opportunities; building sector-relevant knowledge; organizing and distributing knowledge; creating conditions for the application of knowledge, and exploiting knowledge, The creation of conditions for the application of knowledge is an action focused on the generation of sustainable competitive advantages (Xue, 2017).

In addition to strategies, it is necessary to consider the barriers to knowledge management; for Doz, Cuomo, and Wrazel (2007), there are four barriers to the integration of knowledge into business activities, which correspond to diversity of knowledge, dispersion of knowledge, the complexity of knowledge and ownership of knowledge. That implies understanding the dimensions of each one to generate actions that allow overcoming them and thus ensure effective management of the knowledge and experiences available to the organization.

It is worth mentioning that because it is intangible, knowledge is characterized by being complex to understand, share and take root among the sectors of the organization. Using knowledge effectively and consistently is crucial to gaining a competitive advantage. Investing in KM ensures the use of all available knowledge in an organization (Rabeea et al., 2019; Wu and Wang, 2006; Martins et al., 2019).

The Tequila and the value generated by its appellation of origin and knowledge management.

Tequila became the first Denomination of Origin (DO) of Mexico in 1974, which means that it has an intellectual protection model that generates value as a product whose quality and characteristics come exclusively from the geographical environment and from natural and human factors of the place where it is produced (Official Gazette of the Federation (DOF, 2018).

Tequila is considered a symbol of Mexicans for its historical, sentimental, and national value (Olmedo-Carranza, 2010). The value lies in the intrinsic and extrinsic qualities that give it worthy representativeness and motivate to safeguard agave, preserve tequila art, and include Tequila as a gastronomic product of origin and tradition in social, cultural, and economic activity, such as tourism (Schlüter, 2008).

Therefore, the DO of this distillate is a tool for territorial valorization and tourism promotion (Gómez-Cuevas et al., 2020), which has managed, together with the Tequila Regulatory Council (CRT), to control and endorse compliance with the Mexican standard in its production, guaranteeing the consumer its origin and quality (Official Gazette of the Federation,

DOF, (2018).). The Tequila Denomination of Origin (DOT) extends to more countries; today, 44 nations recognize the DOT (mipatente, 2023).

In this context, the value of Tequila has a legacy for the community, as it gives it a sense of belonging that manifests its work, dedication, and part of its essence, in addition to the time it took to create and consolidate the drink (Gómez, 2018). In addition to the above, the denomination of origin that contributes to the product's value positions the Tequila brand and helps preserve and enhance cultural and natural heritage. Industrial and tourist competitiveness would differ (IIEG, 2021). (IIEG, 2022).

3. Methodology

This research was based on a work that modeled the knowledge of experts in the production of Tequila through a Bayes Network (Terán-Bustamante et al., 2022). Next, a data set was obtained from the patterns found in the proposed Bayes network. On the data set, the classification was carried out with the Knowledge Management variable as the objective variable, and it made several experiments to classify the data set. In them, we apply three algorithms for classification Support Vector Machines (SVM), Neural Networks (NN), and Naive Bayes (NB). The metric used to choose the best model was a recall, where we obtained the values 0.573, 0.682, and 0.991 for NB, NN, and SVM, respectively.

In this way, we found that the most relevant variables for the classification process are Ancestral Knowledge, Competitive and Technological intelligence, Customer needs detection, Cultivation of raw materials Agave, Designation of origin based on ReliefF metric (ReliefF measures the ability of an attribute to distinguish between classes on similar data instances).

To have elements to validate the integrity of the results, we apply two methods, the Multiple Criteria decision-making method, and fuzzy logic. The general operation of each of them is described below.

First, it has applied Multiple-criteria decision-making to determine the most relevant factors to achieve the best scenario for Knowledge Management. It is one of the primary decision-making problems which aims to determine the best alternative by considering more than one criterion in the selection process.

We apply the Analytic Hierarchy Process (AHP). AHP is a multi-criteria decision-making method that was proposed in the 1970s by Saaty (Saaty, 2008). It is used to derive ratio scales from both discrete and continuous paired comparisons. These comparisons may be taken from actual measurements or a fundamental scale that reflects the relative strength of preferences and feelings. It has been used extensively for analyzing and structuring complex decision problems. It is a general theory of measurement. AHP is recognized as a valuable method to handle issues with several criteria (Fattoruso, 2023).

The AHP consists of four steps: Identify the decision, options, and criteria; Compare in pairs. It Calculates the importance weight of each criterion; Identifies the best choice by calculating something called utility. In other words, applying the methodology consists of establishing the importance of weights associated with the criteria in defining the overall goal. That is done by comparing the criteria pairwise.

AHP's popularity stems from its simplicity, flexibility, intuitive appeal, and ability to mix quantitative and qualitative criteria in the same framework. AHP has been applied to various decision problems focused on decision-making (Asonitis, 2010).

The first stage of the AHP method consists of establishing the hierarchy of the decision problem by defining the objective; next, the criteria and sub-criteria are specified, then a hierarchical model is elaborated based on element comparison matrices and the use of matrix algebra elements; Finally, once the hierarchical structure of the problem has been built, the elements are assessed, for which the decision maker evaluates the criteria through paired comparisons and considers the different alternatives concerning each criterion, the AHP It allows these comparisons to be made based on both quantitative and qualitative factors, since for them the scale proposed by Thomas Saaty is used, in this way the decision maker can express his preferences between two elements through numerical values. In summary, 1) it offers a numerical ranking according to the classification of alternatives. 2) Allows the use of criteria and sub-criteria. 3) Enables the use of qualitative information. 4) Allows the use of quantitative data. It allows working with a multidisciplinary team.

Next, we use Fuzzy Logic to find the best scenario to achieve Knowledge Management. Considering the selected variables, a model based on Fuzzy Logic (FL) was built, which has a remarkable characteristic that allows building models based on the experience of experts that, like any process where there is human intervention, has value scales that do not they are necessarily exact. There are qualifications for the variables where the scale can be Good, Fair, or Deficient with intermediate values between them, such as Very Good, Good, Almost Good, Fair, Almost Fair, Deficient, or Very Deficient, etc.

In this way, the most relevant variables for the classification were fed, being able to infer the results when mapping the input variables given an output. The process involves membership functions, fuzzy logic operators, and if-then rules. This way, a model involving five input and one output variable was built (Figure 1).

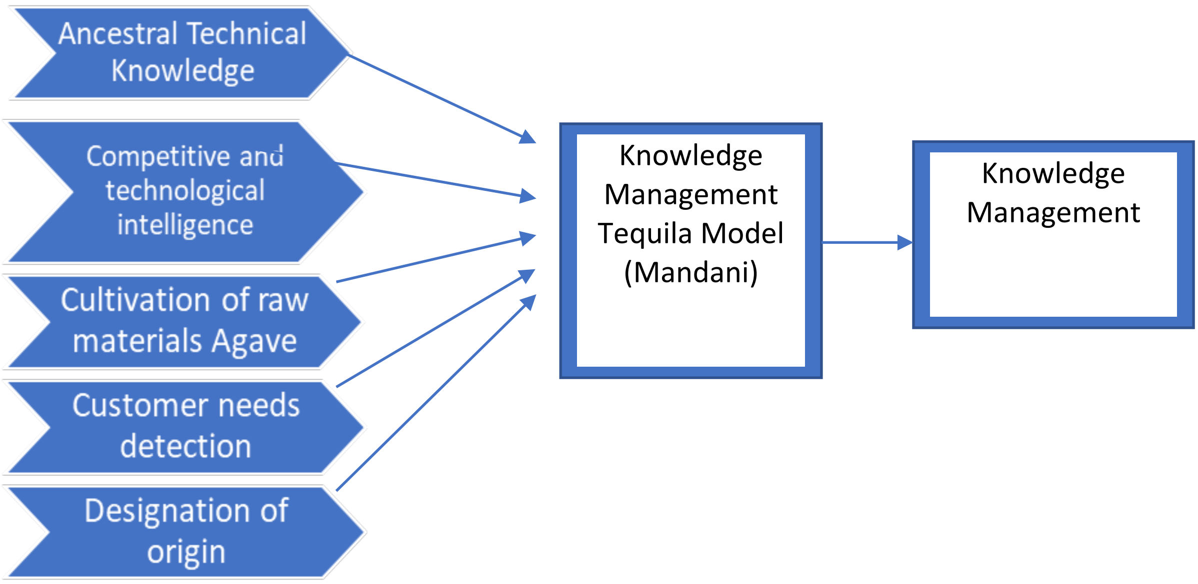


Figure 1: Fuzzy Model

The most straightforward membership functions are formed using straight lines. Of these, the simplest is the triangular membership function, a collection of three points that form a triangle, which has the advantage of simplicity. There are other types of membership functions, such as trapezoidal. A membership function (MF) is a curve that defines how each point in the input space maps to a membership degree between 0 and 1.

Furthermore, fuzzy sets describe vague concepts that admit the possibility of partial membership in them. A membership function associated with a given fuzzy set maps an input value to its appropriate membership value.

Fuzzy logical reasoning operates based on standard Boolean logic. Fuzzy sets and fuzzy operators are the fundamental elements that allow us to build complete sentences. These are the conditional statements, the if-then rules permuted to make valuable inferences. Inferences from a fuzzy rule assign a complete fuzzy set to the output. If the antecedent is only partially true, then the output fuzzy set is truncated according to the implication method. The set of rules competes. The output of each rule is a fuzzy set. However, what is wanted is that the output of an entire collection of rules is a single number (Figure.2).

The input to the defuzzification process is a fuzzy set, and the output is a single number. Given a fuzzy set that spans a range of output values, it is required to return a number, thus going from a fuzzy set to a crisp output.

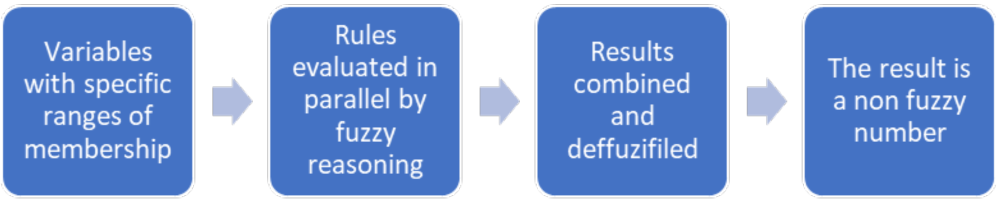


Figure 2: Fuzzy Logic Process

Fuzzy inference systems have been successfully applied in various fields. Due to its multidisciplinary nature, the fuzzy inference system is known as a fuzzy rule-based system, fuzzy expert system, fuzzy model, and fuzzy logic controller, among others.

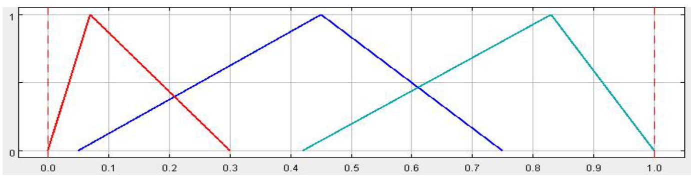
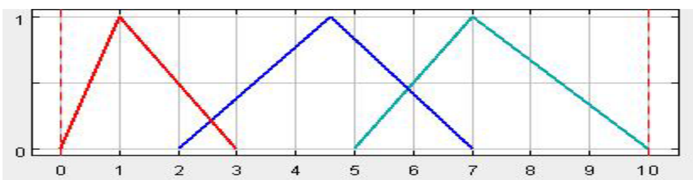
The membership functions are based on the Innovation and Technological Management Model results in the Tequila Sector in Mexico (Terán-Bustamante et al., 2022). Memberships are expressed in terms of probabilities in a Bayes Network Model.

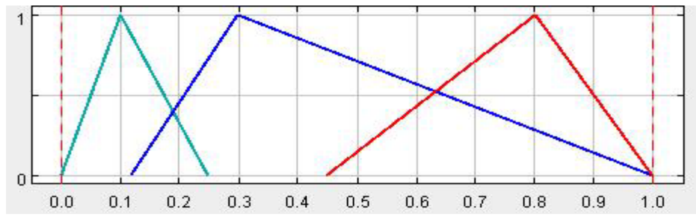
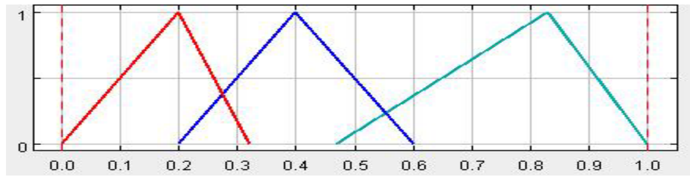
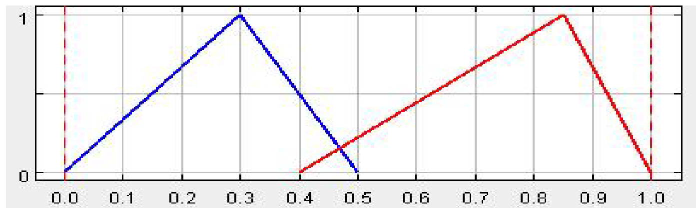
The Fuzzy Logic system was constructed using a Mamdani inference system to obtain the logical implications of the ten rules and five input variables used to build the model (Table 1).

The assigned ranges for the membership functions were given considering the previously assigned crisp values. In this way, sets of fuzzy values were built for each of the parameters assigned to each variable.

A triangular membership function was applied for its efficiency and simplicity. This is explained by employing the graph located in the "membership parameters" column. On the "x" axis, the values that each variable can take are indicated through lines identified with a color code.

Table 1: Fuzzy Logic System Description

Input Variables	Range	Membership Functions	Membership parameters
Ancestral Technical Knowledge	[0,1]	Optimum (Green) Regular (Blue) Deficient (Red)	
Competitive and technological intelligence	[0,1]	Optimum (Green) Regular (Blue) Deficient (Red)	

Input Variables	Range	Membership Functions	Membership parameters
Customer needs detection	[0,1]	Optimum (Res) Regular (Blue) Deficient (Green)	
Cultivation of raw materials Agave	[0,1]	Optimum (Green) Regular (Blue) Deficient (Red)	
Designation of origin	[0,1]	No (Blue) Yes (Red)	

We constructed a set of 10 inference rules that, without trying to be exhaustive, express the possible relations among the input variables based on the knowledge expert (Table 2). Rules must meet some basic standards of completeness, consistency, interaction, and robustness. Completeness: The rules must comply with all possible combinations of inputs so that there are no gaps in which no action is taken. Consistency: Two actions cannot coexist in the same situation, which would produce a contradiction. Interaction: Corresponds to the weight of a rule among the rest; for this, the effect of the rules on the control action must be analyzed. Robustness: It measures the controller's reaction to input disturbances.

The defuzzification step transforms the aggregated fuzzy set into one crisp number using the centroid method. This method returns the area's center of gravity projection under the membership function. Thus, the defuzzification is realized by a decision-making algorithm that selects the best crisp value based on a fuzzy set. The interpretation of these values is the probable value the output variable will have under the inference rules.

Table 2: Inference Rules

Inference Rules	Ancestral	Cultivation	Customer	Origin	Knowledge Management
1	Optimum	Optimum	Optimum	No	0.05
2	Optimum	Optimum	Regular	Yes	0.85
3	Optimum	Regular	Regular	Yes	0.85
4	Optimum	Regular	Deficient	Yes	0.7
5	Regular	Regular	Deficient	No	0.01
6	Regular	Deficient	Regular	Yes	0 75
7	Deficient	Deficient	Deficient	Yes	0.55
8	Deficient	Regular	Regular	Yes	0.56
9	Regular	Optimum	Optimum	No	0.32
10	Regular	Regular	Optimum	No	0.3

Based on the expert's knowledge, the values achieved from the defuzzification process are expressed as a numerical value in the range [0,1] for the output variable (KM).

4. Results, Discussion, and Conclusions

Applying AHP has made it possible to find the optimal values for the combinations of Ancestral Knowledge, Cultivation of Raw materials, Customer needs detection, and Origin denomination factors.

The steps followed to determine the best combination of factors to arrive at the optimal value of KM according to AHP are the determination of comparison criteria, calculation of the weighting for each of the variables, and validation through the value of the ratio of the consistency index, the configuration of the alternative's comparison matrix—finally, the determination of the best combination of factors for Knowledge Management.

The importance of variables comparison was registered in a Criteria Comparison Matrix (Table 3), where the values represent the relative importance based on a range from 3 to 9 according to the Saaty scale. It is based on the opinion of experts on Tequila production as to the importance of the variables about each other.

Table 3: Criteria Comparison Matrix

	Ancestral Technical Knowledge	Cultivation of raw materials Agave	Customer needs detection	Designation of origin
Ancestral Technical Knowledge	1	3	5	5
Cultivation of raw materials Agave	0.333333333	1	3	3
Customer needs detection	0.2	0.333333333	1	3
Designation of origin	0.2	0.333333333	0.333333333	1

Based on the information in the Criteria Comparison Matrix, the weights corresponding to each variable were obtained (Table 4). In this way, the most important variable is Ancestral Technical Knowledge.

Table 4: Calculated Weights for Each Variable

Variable	Weight (Wi)
Ancestral Technical Knowledge	0.54
Cultivation of raw materials Agave	0.24
Customer needs detection	0.14
Designation of origin	0.08

The value assigned for the consistency index is 4, corresponding to the number of variables. In consequence, the Consistency Index Ratio is 0.099. This value is less than 0.10, which validates the calculations made.

Next, the alternative comparison matrices for each variable were elaborated based on the values obtained through the results obtained in the previous work in which the values assigned to each variable in the Bayes Networks were reported (Terán-Bustamante et al., 2022) (Table. 5).

Table 5: Assigned Values to Each Variable

Ancestral Technical Knowledge	Cultivation of raw materials Agave	Customer needs detection	Designation of origin
OPTIMUM	OPTIMUM	OPTIMUM	NO
OPTIMUM	OPTIMUM	REGULAR	YES
OPTIMUM	REGULAR	REGULAR	YES
OPTIMUM	REGULAR	DEFICIENT	YES
REGULAR	REGULAR	DEFICIENT	NO
REGULAR	DEFICIENT	REGULAR	NO
DEFICIENT	DEFICIENT	DEFICIENT	NO
DEFICIENT	REGULAR	REGULAR	YES
REGULAR	OPTIMUM	OPTIMUM	NO
REGULAR	REGULAR	OPTIMUM	NO

The results obtained based on AHP methodology indicate that the combination of values assigned to each variable read by row is shown in Table 6. Where the prioritization value indicates the better combination of values. Combination 1 and combination 2 are the best scenarios to achieve Knowledge Management.

Table 6: Prioritization Results

	Ancestral Technical Knowledge	Cultivation Of Raw Materials	Customer Needs Detection	Designation Of Origin	Prioritization	%
Comb1	0.15	0.18	0.18	0.06	0.15	**15%**
Comb2	0.15	0.16	0.08	0.13	0.15	**15%**
Comb3	0.17	0.08	0.08	0.13	0.13	13%
Comb4	0.17	0.08	0.03	0.13	0.13	13%
Comb5	0.07	0.09	0.03	0.04	0.07	7%
Comb6	0.08	0.05	0.10	0.13	0.08	8%
Comb7	0.03	0.04	0.03	0.13	0.04	4%
Comb8	0.03	0.08	0.09	0.13	0.06	6%
Comb9	0.08	0.18	0.18	0.05	0.11	11%
Comb10	0.09	0.08	0.20	0.04	0.09	9%
Weight (Wi)	0.54	0.24	0.08	0.14	1.00	100%

Next, the procedures corresponding to Fuzzy Logic are applied, and the corresponding results are reported.

Once the Fuzzy Logic Model was applied, the results of the combinations in the fuzzy values of the variables were obtained based on the inference rules fed to the model.

One way to graphically explain the results obtained is through surface plots. Where the influence that each variable has on the objective variable is presented in a three-dimensional graph, where the variables are located on the "x" and "y" axes and the "z" axis, the objective variable is represented.

Based on the inference rules, it is observed that the highest value reached for the objective variable (Knowledge Management) are numbers 2 and 3. In this way, the value achieved by the Knowledge Management variable is explained through the most relevant variables for the classification. For rule 2, the values for the variables Ancestral Technical Knowledge, Cultivation of raw materials, Customer needs detection, and Designation of Origin was optimum, optimum, regular, and yes, respectively. In the same way, in rule 3, the values for the same variables were Optimum, regular, regular, and yes. In both cases, 80% was obtained for the objective variable. That makes it explicit that different combinations of the fuzzy values in the input variables allow us to achieve satisfactory results in the output variable.

Some of the most relevant results are presented below, utilizing surface plots to explain the influence of pairs of variables.

Then, the influence that the variables have on the output variable indicates that the values in the range [0,1] for the Customer needs detection variable and [0.4,1] for the Ancestral Knowledge variable allow obtaining values close to 85 in the variable output Knowledge Management (KM) (Figure 3).

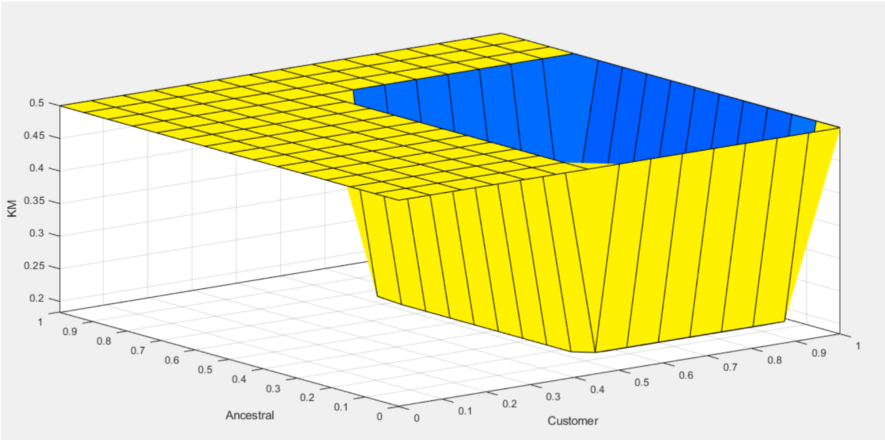


Figure 3: Surface Graph Customers Need Detection vs. Cultivation of raw Materials

For the surface plot corresponding to the Cultivation of raw materials vs. ancestral knowledge variables, it is observed that even if the values for the Cultivation of Raw-Materials variable have values in the range [0,1]. In contrast, the Ancestral Knowledge variable has values in a range of medium to high [0.4,1] to achieve high values in the KM variable (Figure 4).

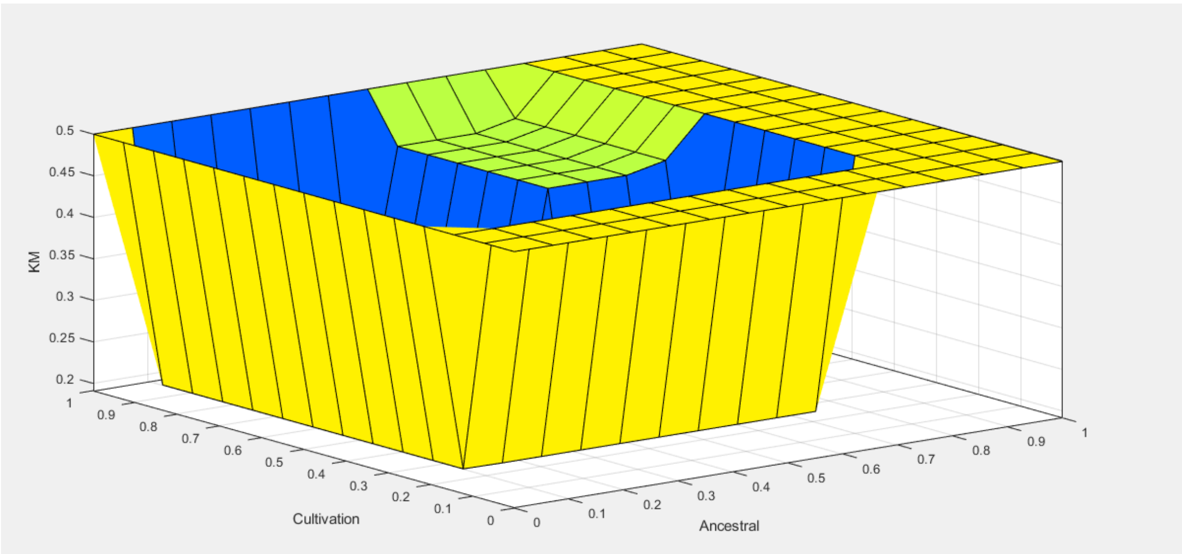


Figure 4: Surface Graph for Cultivation Raw Materials vs. Ancestral Knowledge Variables

Thus, given the characteristics of the complete system, the range of the values for variable Designation of Origin [0.5,1] allows variable KM to reach 85 if the Ancestral Knowledge range of values is in the [0.4,1] range (Figure 5.).

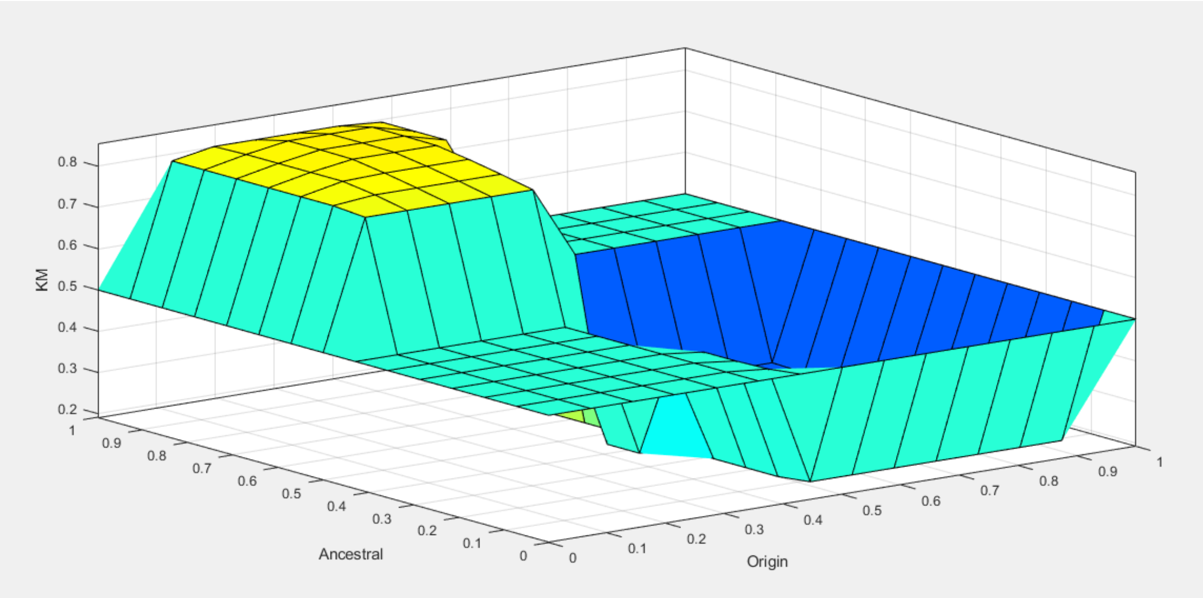


Figure 5: Surface Graph for Designation of Origin vs. Ancestral Knowledge Variables

Based on the results obtained, it is shown that it is possible to achieve satisfactory results in the output variable from the fuzzy sets established as a range for the input variables, considering that humans generally express their knowledge on scales that point values cannot represent.

In summary, the inferences from the system of five input variables and ten inference rules allow us to infer that the Ancestral knowledge variable is the most influential in attaining high values in the Knowledge Management output variable.

5. Conclusions

As can be seen, the Tequila sector has a great tradition in Mexico; it is a fundamental part of the national economy and various regions of the country. The knowledge generated from ancestral values is greatly valued in elaborating this distillate. Thus, it is essential to consider the necessary actions for decision-making for knowledge management in the Tequila sector and generate a model that allows innovation. Knowledge management – through the developer model – is a facilitating system that combines individual and collectible experiences and knowledge, as well as ancestral and technological, to achieve competitive advantages.

It is considering knowledge management as a tool that allows both companies and various sectors of a country to increase their capacity to respond to challenges, changes, crises, and the diverse circumstances of the present and future, with a positive effect on its value when it implies an adequate circulation of ideas and information.

Having a model that allows better decisions, optimal or non-optimal management of knowledge management and its various factors, through the causality of the variables, will enable us to improve decision-making when selecting the factors that better influence to achieve Knowledge Management.

The participation of the State plays the unquestionable role of knowledge and innovation for the development of the economy and society, but also from the specificities of agribusiness. n accordance with the above, the agricultural and scientific policies implemented by the State and the participation of various institutions, such as universities and research centers, which operate in the agribusiness environment, play a crucial role in the sustainability and quality of life of the community's people. For their part, institutes and universities allow and facilitate the link between the various actors while making the best use of the research potential to achieve it (Farrukh et al., 2017; Piotr, 2019).

In summary, an adequate knowledge management strategy in the Tequila sector in Mexico facilitates the appropriation and integration of knowledge from various sources, stimulates the creation of new knowledge and innovative action, and contributes to the generation of competitive advantages and sustainability over time both to the sector and to the various rural communities involved. At the same time, it allows decision-makers and public policymakers to generate programs that will enable the sustainability of this sector.

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