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Location of companies using fuzzy logic: Strategy for positioning

Localización de empresas usando lógica difusa: estrategia para su posicionamiento

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Abstract

This research consists of determining the optimal location in the certainty and uncertainty (diffuse environment) of a company dedicated to the production of avocado derivatives in the State of Michoacán taking into account objective and subjective factors. For this, the methodology proposed by Brown and Gibsosn (1972) - (B and G) will be used, it is presented in classical theory, and the analysis is done in an uncertainty environment using fuzzy logic, this approach has not been reported in the specialized literature for the treatment of the reference methodology. To obtain information (data) a panel of 5 experts is incorporated into the methodology of (B and G). The results obtained using fuzzy logic are efficient and effective, obtaining the optimum location in the community of San Juan Nuevo Parangaricutiro. From the above it is necessary that the application of (ByG) using NBT in the study of location of companies, provides information not provided of origin that is very valuable to strengthen the decision making and design and implementation of strategic business development plans.

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Resumen

Esta investigación, consiste en determinar la ubicación óptima en la certeza e incertidumbre de una empresa dedicada a la producción de derivados del aguacate en el Estado de Michoacán, para ello toma en consideración factores objetivos y subjetivos. En este estudio se usará como base la metodología propuesta por Brown y Gibsosn (1972)- (B y G), la misma es presentada en teoría clásica, además se hace el análisis en un ambiente de incertidumbre usando lógica difusa, este enfoque no se ha reportado en la literatura especializada para el tratamiento de la metodología de referencia. Para la obtención de información (datos) se incorpora a la metodología de (B y G) apoyada por un panel de 5 expertos. Los resultados obtenidos usando lógica difusa, son eficientes y eficaces, se obtiene la ubicación óptima en la comunidad de San Juan Nuevo Parangaricutiro. De lo anterior se tiene que la aplicación de (ByG) usando números borrosos triangulares (NBT) en el estudio de localización de empresas, en el estudio se obtiene información no proporcionada de origen que es muy valiosa para fortalecer la toma de decisiones y diseño e implantación de planes estratégicos de desarrollo empresarial.

Código JEL: C69, C83, L1
Palabras clave: Localización; Óptimo; Factor básico localizacional; Empresa; Competitividad; Lógica difusa

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Introduction

In both public and private companies producing final, intermediate, and capital consumption goods and services, determining the site (location) where they should be installed is a strategic element for the economic development of any country, region, or locality. According to González Santoyo et al. (1985) and Flores Garrido L. et al. (2016), the location of a company (plant) is represented by the site or unit of geographic area (Ai, $i = 1,2,\ldots,n$) in which it carries out its production or provision of services, as well as its commercial transactions, so as to guarantee the highest level of financial profitability and full social acceptance. According to the UN (1958) and Bojic S. et al. (2018), the most suitable method of location for a company lies in selecting a locality that guarantees the highest level of profitability from the perspective of private investment, and a locality that allows for the lowest operating costs if considering a social approach.

To define the geographic area (macro-micro level) (Ai), it is important to consider whether the location is market-oriented (closest location to the market area), or if it is raw materials and inputs oriented (location closest to these), that is, inputs and raw materials with a significant economic impact.

The decentralization policies of the State are an important element to consider in this analysis. There will be cases in which development will be sought for a particular part of the country, state, or municipality, creating fiscal incentives or other benefits for the investor.

The above is relevant since current organizations are being confronted with significant changes in the environment. For Castro García *et al*. (2010), the market is very competitive, and globalization nowadays is a reality. The implication for any entrepreneur is to operate in the same conditions of competition. A fundamental factor in business development is the efficient and effective location of companies. González Santoyo F. et al. (2011) and Jeong J.S. and Ramírez G.A. (2018) consider that a strategic plan of multifactorial development should be incorporated in order to address location, as well as the conditions of the possible areas of interest given by (Ai), and those of the environment.

According to Machuca et al. (1994), the location decisions of a plant are generally taken just once for the company, without ruling out the possibility of relocating because it does not meet the needs required by the plant for its operation, which would imply a drop in its operating profitability.

According to Tawfik *et al*. (1993), among the most common problems encountered when a company is not suitably located are: distance from consumer markets; problems with the supply of raw materials, inputs, and services; problems in the availability of skilled labor; and increased transportation costs.

Similarly, Garret (1973) and Dilworth, J.B. (1993) establish that the most important factors when locating a company are: changes in demand, changes in demand distribution, high transportation costs for materials and inputs, relocation due to community rejection or environmental issues, relocation due to security issues, and exhaustion of sources of supply.

In solving the location problem of companies, three components need to be defined; these are the selection of the region, the determination of the locality within the region, and the selection of the site where the company will be located. The above will be associated with what is known as Macro-location and Micro-location.

According to Medina J.R. *et al*. (2009), the objective of Macro-location is to determine the region or territory in which there is an interest in the location of the plant. This interest can be international, national, or local; therefore, it is fundamental to determine the basic localization factors {BLFi; i=1, 2, …, n} according to their geographical scope. For Kavita D. and Shiv Prasad Y. (2013), the following are among the most important factors:

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Socioeconomic and cultural aspects: total population, economically active population, economic sectors (activity branches), salaries and wages, education, public health, and current power structure.

Infrastructure: modes of communication, electrification, irrigation works, potable water networks, collection and storage centers, and communication technologies.

Institutional aspects: property regulations, credit institutions, and government development programs.

Analysis of consumer markets: geographic dispersion of demand.

Availability and costs: raw materials, auxiliary inputs, labor, technical assistance, electricity, water, and fuels.

Transportation costs: raw materials and auxiliary inputs, and products and byproducts.

Geographic factors: ecological phenomena, topographic conditions.

Institutional factors: decentralization policies, planning policies by economic sector, and fiscal incentives.

For González Santoyo F. (2005), the objective of Micro-location is to define the locality where the plant should be located, looking for a site that guarantees the highest profitability or the greatest benefit-cost (B/C) ratio. The selected site shall be that which more efficiently and effectively meets the set of basic localization factors expressed as $\{BLF_i; i=1, 2, \ldots, n\}$.

Most existing models in the literature used for company localization only include quantitative factors. The few models that include qualitative factors use ordinal scales for their completely arbitrary measurements. The implication is that this type of methodology is rigid and has little flexibility to represent reality; therefore, it is important to use new methodologies such as fuzzy logic.

The mathematical models currently used for the efficient and effective decision-making for the localization of a company are based on the classical theory of sets and Operations Research, which, in terms of bivalent logic, consider that an element can only be within it or not. According to Klir *et al*. (1995), S. Melkote and M. Daskin (2001), and A. Klose and A. Drexl (2005), the movement of the elements from one set to another occurs gradually and not through chaotic and accelerated steps. For example, if a locality at first considered unsuitable for the location of a company is gradually improved and has changes in its demographic structure and socioeconomic environment, among other factors, it can transform itself into the best possible alternative to locate a company from the perspective of human appreciation when it is realized that said locality is improving.

Decisions based on how human beings think would seem not to work directly with numbers associated with measurable variables. From the performance of human thought arises the theory of Fuzzy Logic, which recognizes and makes it possible to express gradual transitions between the membership and non-membership of the elements integrated into the sets. It is formalized based on the function of membership, which allows for the measuring of the degree of compatibility between an observed value and the associated concept, an approach that allows for a better approximation to reality. This study incorporates subjective localization factors.

For Anton B. *et al.* (2010) and Fazel Zarandi M. and Beck J.C. (2012), there is an infinity of methods in the theory of company localization. This study focuses on the company localization process taking the State of Michoacán, Mexico, as reference. The analysis uses the Brown and Gibson (1972) model. The objective is to propose a support method for decision-making in the field of company localization that incorporates a set of basic localization factors expressed by $\{BLF_i;\ i=1, 2, \ldots, n\}$. A panel of 5 experts would be incorporated to qualify these factors using the Delphi method to obtain the information for the analysis, which defines the importance of each factor in the assignment process of its weight (importance-weight). This study, using the B&G model, has an extension to what currently exists in specialized literature, making it apt for evaluating company localization in an uncertain environment (fuzzy).

The organization of this study is as follows: 1. Introduction - presents the topic landscape of plant localization; 2. Proposed methodology - presents the methodology of interest in a deterministic environment; 3. Case analysis - evaluated in a deterministic environment, and references the methodology to be used in an uncertain environment (fuzzy); Conclusions and Bibliography.

Proposed methodology

This study proposes the B&G model for the analysis of company localization, a method that makes it possible to combine quantifiable objective factors with subjective factors possible to evaluate in relative terms. For this method to be effective the localities of interest take as reference the country, region, city, and municipality levels, among others, that comply with the set of basic localization factors $\{BLF_i;\ i=1, 2, \ldots, n\}$ required, discarding all proposals that do not meet the minimum level established by the panel of experts. These factors, due to the complexity of estimating their importance, are classified as *objective* and *subjective* factors. The reference methodology is composed of the following stages:

1. Assign a relative value to each objective factor (OF_i; i=1, 2, …, n) for each viable locality of interest used in the analysis.
2. Estimate a relative value for each subjective factor (SF_i; i=1, 2, …, n) for each locality of interest incorporated in the analysis.

3. Combine the objective and subjective factors, and assign them a relative weight, to obtain a measure of location preference (MLP_i; i=1, 2, …, n).
4. Select the location with the highest measure of location preference in the evaluation of point (3) above.

In order to operationalize the methodology in stage (1) *Relative value of the objective factors* {OF_i; i=1, 2, …, n}, it is possible to quantify these factors in terms of cost, making it possible to obtain the total annual cost of each localization alternative (C_i). Therefore, (OF_i; i=1, 2, …, n) is determined by multiplying the (C_i) of each locality of interest considered in the study by the sum of reciprocal costs ($1/C_i$) and taking the reciprocal of the result. This calculation uses Equation (1) below:

$$OF_i = \left[C_i \sum_{i=1}^{n} \left(\frac{1}{C_i}\right)\right]^{-1} \tag{1}$$

Where:

C_i = cost of each basic localization factor

The sum of (OFi; i=1, 2, …, n) will always have a maximum equal to the unit. Thus, the assumption is that each of those factors is always a relative term between the different alternatives used in the localization analysis.

In stage (2) *Relative value of the subjective factors* (SFi; i=1, 2, …, n), the study uses Equation (2) below:

$$SF_i = \sum_{j=1}^{n} R_{ij} \, W_j \tag{2}$$

Where:

W_j = relative importance index of each localization factor concerning other factors considered.

R_{ij} = relative score assigned by the evaluation of the localizations in paired comparisons.

The following conditions must be considered:

$$\left(0 \leq R_{ij} \leq 1, \sum_{i=1}^{n} R_{ij} = 1\right)$$

In the paired comparison analysis, a value of **1** indicates the basic localization factor is the most relevant, and a value of **0** indicates the least important. In the case of {BLFi; i=1, 2, …, n}, when more than one variable is considered to be equally important, they are assigned a value of **1**.

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For stage (3) *Measure of location preference* (**MLP**), the objective and subjective factors must be evaluated first to then calculate the location preference using Equation (3) below.

$$MPL_I = K(FO_i) + (1 - K)(FS_i) \tag{3}$$

The relative importance that exists between the objective and subjective localization factors is obtained by assigning a weight (K) to one of the factors and its supplement (1-K) to the other type of factors, such that relative importance is expressed between them. The above uses a 0 to 10 scale of how much more important a type of factor is with respect to the others. Therefore, *the best place to locate a company is the one that complies with the* ***Max.{MLP$_i$}*** *criterion*. The implication is that a change in the weights assigned to the factors can lead to other decisions because it would entail an evaluation using different scenarios.

Stage (4) uses Equation (4), which results in the optimal site to locate the plant.

$$max.\{MPL_i\} = K(FO_i) + (1 - K)(FS_i) \tag{4}$$

Case analysis

Analysis using classical theory (use of clear numbers)

The analysis will use the case of the avocado corporation of Meseta Tarasca, which is interested in investing in the State of Michoacán, Mexico. Said organization wants to begin its economic activity with a company that produces avocado derivatives. Currently, the corporation has four possible sites to locate the company, with a preference for the populations of Uruapan (U), Apatzingán (A), Morelia (M), and San Juan Nuevo Parangaricutiro (SJN). The panel of experts considers that the above localities comply with most of the basic localization factors $\{BLF_i; i=1, 2, \ldots, n\}$, as well as the acceptance of the population of each locality, which is fundamental to preserve social stability and wellbeing when installing the company in any of said localities. The analysis uses the methodology described in Section (2).

In Stage (1), the costs (C_i) for each locality are expressed by unit (p.u.-$), which are different for each locality. A cost analysis for each of the reference localization factors provides the results presented in Table 1.

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Table 1
Associated Costs

CONCEPT\ Cost (p.u-$)	U	A	M	SJN
Raw materials	8.5	9.5	10.0	8.5
Labor	9.4	10.0	8.5	9.0
Transport	8.6	9.6	10.0	8.0
Electricity	9.4	9.4	9.5	9.4
Cost of the land	10.0	8.5	8.0	9.0
Water supply	7.0	7.0	7.5	7.0
Inputs	8.5	9.0	7.0	8.5
TOTAL (C_i)	61.4	63	60.5	59.4
Reciprocal ($1/C_i$)	0.01628	0.01587	0.01652	0.01683

Source: own elaboration

The total of ($1C_i$) is equal to 0.0655, which will be the basis to calculate the *objective qualification factor* for each locality, the results for which are presented in Table 2.

Table 2
Objective Qualification Factor

LOCALITY		OF_i
U	0.01628/0.0655	0.248549618
A	0.01587/0.0655	0.242290076
M	0.01652/0.0655	0.25221374
SJN	0.01683/0.0655	0.256946565
TOTAL		1.0

Source: own elaboration

In Stage (2), it is necessary to analyze the relative importance index (W_j) and the hierarchical order index (R_{ij}), using Equation (2), to analyze the ***subjective factors*** (**SF_i**).

For the installation of the company in the locality, the study considers the following as *subjective factors*: education, climate, housing, population acceptance. The paired evaluations will assign a value of (**1**) to the most relevant factor, and a value of (**0**) to the least relevant. In the case of factors with equal levels of relevance, their assigned value will be of (**1**).

First, the panel of experts will establish the determination of the ***relative importance factor*** (W_j), calculated using the probability calculation criteria of an event P(A)—established by Laplace in the 17th century. Table 3 presents the obtained values for (W_j).

Table 3
Calculation of the relative importance factor

FACTOR (i)	Paired comparisons				Preference sum	W_j
	U	A	M	SJN		
Education	1	0	0	1	2	2/7=0.2858
Climate	0	1	1	0	2	2/7=0.2858
Housing	0	0	0	1	1	1/7=0.14286
Community acceptance	1	0	0	1	2	2/7=0.2858
TOTAL					7	1.0

Source: own elaboration

The *Hierarchical Order Index* (R_{ij}) is calculated using the criteria established to obtain the results presented in Table 3, and it represents the relative importance of each localization factor as a function of the site of interest. The tables below present the analysis for each factor.

Table 4
Education

FACTOR (i)	Paired comparisons				Preference sum	R_{iU}
	1	2	3	4		
A	1	0	0	0	1	1/6=0.16666
U	0	1	1	0	2	2/6=0.33333
M	0	0	0	0	0	0
SJN	1	1	1	0	3	0.5
TOTAL					6	1.0

Source: own elaboration

Table 5
Climate

FACTOR (i)	Paired comparisons				Preference sum	R_{iE}
	1	2	3	4		
A	0	1	0	1	2	0.28571
U	0	1	0	0	1	0.1426
M	0	0	0	0	0	0
SJN	1	1	1	1	4	0.57142
TOTAL					7	1.0

Source: own elaboration

Table 6
Housing

FACTOR (i)	Paired comparisons				Preference sum	R_{iE}
	1	2	3	4		
A	1	0	0	0	1	0.16666
U	0	1	0	0	1	0.16666
M	1	0	0	1	2	0.33333
SJN	1	0	0	1	2	0.33333
TOTAL					6	1.0

Source: own elaboration

Table 6
Community acceptance

FACTOR (i)	Paired comparisons				Preference sum	R_{iC}
	1	2	3	4		
A	0	0	0	1	1	0.1428571
U	1	1	0	0	2	0.285714
M	0	0	0	0	0	0
SJN	1	1	1	1	4	0.571428
TOTAL					7	1.0

Source: own elaboration

Table 7 presents the calculation of the different indicators of the *Hierarchical Order Index* (R_{ij}) and the *relative importance factor* (W_j).

Table 7
Hierarchical Order Index

FACTOR (i)	(R_{ij})				W_j
	U	A	M	SJN	
Education	0.333333	0.166666	0	0.5	2/7=0.2858
Climate	0.142666	0.285711	0	0.571422	2/7=0.2858
Housing	0.166666	0.166666	0.33333	0.333333	1/7=0.14286
Community acceptance	0.285714	0.142857	0	0.571428	2/7=0.2858
TOTAL					1.0

Source: own elaboration

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In order to finalize Stage (2), the *Subjective Factors* (SF_i) for each locality are calculated using Equation (2) described in Section (2) of the methodology.

Taking the locality (**SJN**) as an example:

SF_{SJN}=0.5(0.2858)+0.57142(0.2858)+0.3333(0.14286)+0.571428(0.2858)=0.5171441.

Using the same methodology as in the previous example, Table 8 presents a summary of the calculations for the different localities established as being of interest for the study.

Table 8
Subjective Factors (SF_i)

(FS_i)	LEVEL OF IMPORTANCE
SJN	0.5171441
M	0.04762
U	0.2414872
A	0.193927
Σ	1.0

Source: own elaboration

For the results of Stage (3), the calculation for the *measure of location preference* uses Equation (3) described in Section (2).

For the weight (K) assignment of the objective factors (OF_i) and (1-K), and of the subjective factors (FS_i). In the analysis, the panel of experts considers and recommends that the objective factors be 2.5 times more important than the subjective factors. Therefore, K = 2.5(1-K), that is, K=0.625.

(1-K) = (1-0.625) = 0.375

Using Equation (3), the calculation for the case of (SNJ) is:

MLP_{SJN}=0.625(0.25694)+0.375(0.51714) = 0.354515

Table 9 presents a summary of the results for the different levels of preference:

Table 9
Levels of Preference

(MLP_I)	LEVEL OF PREFERENCE
SJN	0.354515
M	0.17548875
U	0.2458925
A	0.22415125

Source: own elaboration

Stage (4) has $Max\{MLP_I\}=Max\{0.354515, 0.17548875, 0.2458925, 0.22415125\}=0.354515$, obtaining (SJN) as the optimal recommended locality using classical theory analysis.

evaluation in uncertainty (fuzzy logic)

In the economic, social, and technological environment of the company, its activity is much less predictable, and it is in a more unstable situation than in the past. This has motivated from the macro and microeconomic point of view, looking for new methodologies for what economic systems and companies are going. Currently, companies are facing problems such as *localization*, which demand decision-making in an environment where the intended goals appear in an imprecise manner. Therefore, the new decisional context of analysis in the company has gone from determinism to randomness, and from there to dealing with uncertainty (using fuzzy logic) when imprecision formalizes through situations where there is a continuum between belonging and not belonging.

This section is an extension of the original methodology described in Section (2). It is written in an uncertain environment using Fuzzy Logic, and it also incorporates a panel of experts to obtain and validate the information used in the analysis.

In a fuzzy environment, there are an abundant number of relevant works that make applications using multicriteria optimization-based approaches. Kavita D. and Shiv Prasad Y. (2013), for example, consider that the base knowledge of the decision-makers is vague and imprecise, using a TFN based intuitionist method, as well as using qualitative approaches in the selection of the localities of interest. Chu TC (2002a, b), meanwhile, addresses the establishment of the order of preferences by similarity. Similarly, Hwang CL and Yoon K. (1981) present a methodology based on evaluating linguistic criteria and assigning weight and importance using fuzzy numbers. Young D. (2006) proposes the TOPSIS method, going from fuzzy to clear numbers. Chen CT (2001) presents a proposal based on evaluating alternatives

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using TFNs. Chou *et al*. (2008) present the MCDM fuzzy module to select the location of a tourist hotel. Zajim Aljicevic *et al*. (2016) and Zajim A. *et al*. (2018) use MATLAB in a fuzzy environment using TFNs for renewable energy projects.

In the case of the object of this research, the ideas established in the previous works, which use multicriteria optimization, are taken as a reference. The works taken as a base are those that contribute to developing the presentation of the B&G model in a fuzzy environment, mainly those of Zadeh L.A. (1965), Kaufmann A. and Gil Aluja J. (1994), González Santoyo F., Flores Romero B., and Gil Lafuente A.M. (2010), González Santoyo F., Flores Romero B., Gil Lafuente A.M. (2011), Jeong J.S. and Ramírez G.A. (2018). These works use triangular fuzzy numbers (TFNs), also used in the B&G extension for a fuzzy environment, establishing the following:

The symbol $\tilde{A}$ represents a fuzzy number, which comprises a finite or infinite sequence of confidence intervals with the following properties:

- Affects each confidence interval within a value of $\alpha \in [0,1]$, such that two different confidence intervals cannot have the same (α); this value is called the level of presumption.
- $A_{\propto} = [r(\alpha), m(\alpha),]$ designates the confidence interval of level (α) and it must fulfill: $\alpha' < \alpha \Rightarrow A_{\propto} \in A'_{\alpha} \in [0,1]$.

Therefore, a triangular fuzzy number (TFN) is a generalization of the concept of confidence interval. Instead of a unique confidence interval, a family that satisfies the above conditions is considered. For this type of number, their membership functions are linear, as shown in Figure 1.

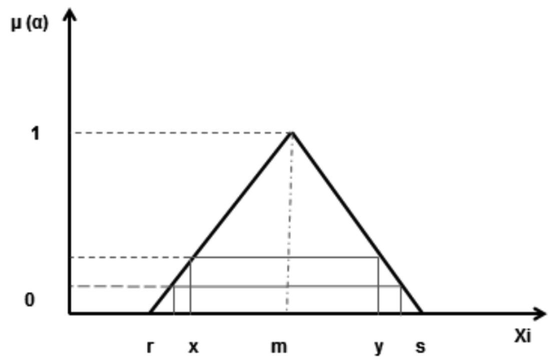

Figure 1. Representation of a TFN
Source: own elaboration

As illustrated in its representation above, three singular points represent it as $\tilde{A} = NBT = (r, m, s)$, with (r, m, s) $\in$ **R** and r$\leq$ m $\leq$ s, therefore establishing that:

For every x $\leq$ r ; $\mu_\alpha\ (x) = 0$; and for every x $\geq$ s ; $\mu_\alpha\ (x) = 0$; $\mu_A\ (m) = 1$

Therefore, the conceptualization of using FTNs allows for adequate estimations in the field of economics and business, as in the case object of this study since it is possible to determine (r) and (s), which correspond to the minimum and maximum estimations, respectively, and an (m) value that represents the highest presumption value or the one with the highest probability of occurrence, in addition to the great adaptability of FTNs to the structure of human thought. The information used in this research is represented using FTNs.

According to the methodology used in this work, for Stage (1), the level of costs is handled by unit-pesos (p.u.-$), and Table 9 presents the quantification according to the panel of experts.

Table 9
Level of Associated Diffuse Costs

CONCEPT\ Cost (p.u-$)	U (r,m,s)	A (r,m,s)	M (r,m,s)	SJN (r,m,s)
Raw materials	(7, 8.5, 9)	(9, 9.5,10)	(9,10,10.5)	(8,8.5,9)
Labor	(9, 9.4, 10)	(9,10,11.5)	(8,8.5,9)	(8,9,9.2)
Transport	(8, 8.6, 9)	(9,9.6,10)	(9.5,10,10.5)	(7.9,8,8.4)
Electricity	(9, 9.4, 10)	(9,9.4,9.8	(9,9.5.10)	(9,9.4,9.8)
Cost of the land	(9, 10, 11)	(8,8.5,9)	(7.5,8,8.5)	(8.5,9,9.2)
Water supply	(6, 7 , 8)	(6,7,8)	(7,7.5,8)	(6.5,7,7.5)
Inputs	(8, 8.5, 9	(8,9,10)	(6.5,7,7.5)	(8,8.5,9)
TOTAL ($\widetilde{C_\iota}$)	(56, 61.4, 66)	(58,63,68.3)	(56.5,60.5,64)	(55.9,59.4,6.1)
Reciprocal (1/ $\widetilde{C_\iota}$)	(0.1515, 0.16286, 0.01785)	(0.014681,0.015873, 0.01724)	(0.01525,0.016528, 0.0176991)	(0.0161,0.01683, 0017889)

Source: own elaboration

In order to calculate the *objective qualification* factors, the fuzzy transformation is as follows:

$$\widetilde{FO_\iota} = \ [\widetilde{C_\iota} \sum_{i=1}^{n} (\frac{1}{\widetilde{C_\iota}})]^{-1} \tag{5}$$

Where:

$\widetilde{C_\iota}$ = (r,m,s) = value of the FTN for each locality

$(\frac{1}{\widetilde{C_\iota}})$= inverse of each FTN level for each locality

The calculation of the *Objective Qualification Factor* $\widetilde{FO_\iota}$ for each locality of interest is done using Equation (5), for which Table 5 presents the results.

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Table 10
Diffuse Objective Qualification Factor

LOCALITY	$\widetilde{FO_\iota}$
U	(0.21435, 0.24859, 0.290168)
A	(0.20715, 0.24229,0.2825)
M	(0.22107, 0.25229.0.28771)
SJN	(0.22779, 0.25690, 0.29080)

Source: own elaboration

In Stage (2), in order to determine the *relative importance index* $\widetilde{W_J}$ and the *hierarchical order index* $\widetilde{R_{\iota J}}$, a panel of 5 experts provided their opinion for consideration. Due to the opinion being provided by human beings, the information is, by its very nature, imprecise-approximate, and is not calculated using any classical mathematical criterion. According to the information provided by said panel of experts, the calculation for the two reference indices used the fuzzy mean added value; the information is as follows:

Table 11
Relative Importance Index in Uncertainty

Factor (i)	$\widetilde{W_J}$
Education	0.15
Climate	0.3
Housing	0.15
Community acceptance	0.4
Total	1

Source: own elaboration

For:

Table 12
For Education in an Uncertain environment

Factor (i)	$\widetilde{R_{\iota J}}$
A	0.4
U	0.1
M	0.1
SJN	0.4
Total	1

Source: own elaboration

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Table 13

For Climate in an Uncertain environment

Factor (i)	$\widetilde{R_{ij}}$
A	0.3
U	0.4
M	0.2
SJN	0.1
Total	1

Source: own elaboration

Table 14

For Housing in an Uncertain environment

Factor (i)	$\widetilde{R_{ij}}$
A	0.3
U	0.2
M	0.1
SJN	0.4
Total	1

Source: own elaboration

Table 15

For Community acceptance in an Uncertain environment

Factor (i)	$\widetilde{R_{ij}}$
A	0.3
U	0.1
M	0.1
SJN	0.5
Total	1

Source: own elaboration

From the above, taking the methodology described in Section (2), the expression of $\widetilde{\boldsymbol{R}_{ij}}; \widetilde{\boldsymbol{W}_j}$ in an uncertain environment is as follows:

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Table 16
Factors $(\widetilde{R_{ij}}; \widetilde{W_j})$

FACTOR (i)	$\widetilde{R_{ij}}$				$\widetilde{W_j}$
	A	U	M	SJN	
Education	(0.3,0.4,0.5)	(0.5,0.1,0.5)	(0.05,0.1,0.015)	(0.3,0.4,0.42)	(0.14,0.15,0.16)
Climate	(0.2,0.3,0.4)	(0.38,0.4,0.42)	(0.1,0.2,0.25)	0.02,0.1,0.15)	(0.2,0.3,0.35)
Housing	(0.1,0.3,0.4)	(0.1,0.2,0.25)	(0.05,0.1,0.15)	(0.3,0.4,0.45)	(0.14,0.15,0.16)
Community acceptance	(0.2,0.3,0.4)	(0.05,0.1,0.15)	(0.04,0.5,0.6)	(0.4,0.5,0.6)	(0.3,0.4,0.5)

Source: own elaboration

Similarly to the analysis above, the *subjective factors* are calculated using Equation (6) to transform the use of Fuzzy Logic. The results for each locality are as follows:

$$\widetilde{FS_i} = \sum_{i=1}^{n} \widetilde{R_{ij}}\ \widetilde{W_j} \tag{6}$$

Table 17
Subjective Factors ($(\widetilde{FS_i})$)

$(\widetilde{FS_i})$	LEVEL OF IMPORTANCE
A	(0.234,0.315,0.46)
U	(0.141,0.205,0.286)
M	(0.046,0.13,0.1435)
SJN	(0.208,0.35,0.4917)

Source: own elaboration

For Stages (3) and (4), using the same criteria as for the classical case, determining the fuzzy $\widetilde{\boldsymbol{MLP}_i}$ is done by using the information expressed in a fuzzy environment obtained through Equations (5) and (6); therefore obtaining the criterion to determine the correct decision to locate a plant uses Equation (7) as follows:

$$\boldsymbol{max\,\widetilde{M}LP_I = k\left(\widetilde{FO_I}\right) + (1-k)(\widetilde{FS_i})} \tag{7}$$

If K = 0.625; (1-K) = (1-0.625) = 0.375

Therefore, the levels of preference obtained using Equation (6) are:

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Table 18
Fuzzy Levels of Preference

$\widehat{MLP_\iota}$	LEVEL OF PREFERENCE
U	(0.066271, 0.092411, 0.125385)
A	(0.100696, 0.133268, 0.190015)
SJN	(0.092236, 0.147306, 0.20255)
M	(0.031066, 0.064518, 0.071791)

Source: own elaboration

For Stage (4), the selection for best localization is the locality of SJN as indicated below:

$Max\{\widehat{MLP_\iota}\} = \{$ (0.066271, 0.092411, 0.125385), (0.100696, 0.133268, 0.190015), (0.092236, 0.147306, 0.20255), (0.031066, 0.064518, 0.071791) $\}$= (0.092236, 0.147306, 0.20255).

Conclusions

The conclusion, based on the analysis carried out to determine the localization of a company using the B&G model with deterministic information and in uncertainty (Fuzzy Logic), as described in the previous sections, is that the incorporation and determination of objective and subjective localization factors, as well as including the opinion of a panel of 5 experts in the analysis of the basic localization factors of reference, leads to more efficient and effective decision-making in selecting the best site (locality) to set up a company, fulfilling the set of $\{BLF_i; i=1, 2, \ldots, n\}$. For this purpose, the methodology proposed for the analysis in both a certain and uncertain environment (Fuzzy Logic) fulfills the requirements to recommend the population of San Juan Nuevo Parangaricutiro, Michoacán, Mexico, as the optimal locality that guarantees the minimum operational cost and the highest level of benefit to the investor.

The study assigns great importance to the availability, cost, proximity, and sufficiency of raw materials and inputs in the planning horizon of the company of interest. Therefore, the conclusion reached is that the use of Fuzzy Logic is a tool that guarantees alternative decision-making processes to those used in classical theory written in bivalent logic, which expresses the space for solutions with a concrete value in line with real numbers, while the evaluation of uncertainty uses fuzzy logic. The answer shall always be an interval with infinite solutions depending on the partitions made in the solution interval represented by a

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fuzzy number. In the present case, this number is a TFN, meaning there are only three values expressed: the lower limit, the highest value, and the upper limit where the solution to the problem is given; this is because it is working with a knowledge base written with multivalent logic, unlike the classical case; thus, this type of analysis is more efficient and effective.

The implication is that having a company in an optimal localization contributes to it being more competitive in the local, regional, national, and international market in its respective economic field.

Future lines of research in this field should make extensions to existing optimization methods in the field of Operations Research, making proposals to shift to the fuzzy environment, as well as comparing efficiency and efficacy between the results obtained in the classical and fuzzy environments.

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