







Article

Assessment urban transport service and Pythagorean Fuzzy Sets CODAS method: A case of study of Ciudad Juárez

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Abstract: The purpose of this research article is to provide a comprehensive method that allows the evaluation of the public transportation in their different transport lines that offer in Ciudad Juárez, Chihuahua. This study presents a description of the public transport system as part of the literature review that describes an appropriate model based on the more outstanding publications about urban mobility and public transportation for passengers' as well as success cases published which serves as a starting point to check the actual state of the public transportation system based on the Pythagorean Fuzzy CODAS to analyze and evaluate the alternatives through criteria that defines the general performance. The integration of these methods provides an adequate methodology for decision-making concerning urban planning and mobility to detect and improve the performance of criteria not considered within sustainable urban mobility plans.

Keywords: CODAS; Pythagorean Fuzzy Sets; Public Transportation; COVID-Criteria

1. Introduction

The tendency in the search for problems of transportation and urban mobility solutions, as well as in urban planning and Geographic Information Systems (SIG), has increased in the worldwide, especially when talking about public passenger transportation because there is an area of opportunity to implement public politics in cities with high population density. In other words, it is necessary to make objective and impartial decisions, that is with a technical approach that helps to cover all the relevant aspects that affect the quality. However, the greatest obstacle that has arisen is the integration of qualitative information within the projects with a large number of criteria to assess the quality of the service provided by a public transportation system are usually obtained thought opinions and interpretations of the users and experts, that is why the contribution of multicriteria decision methods (MCDM) to reduce the bias and improve information analysis is highlighted. One of the most important sets are the Pythagorean Fuzzy Sets (PFS) considered a new generation of the Fuzzy Sets (FS) and Intuitionistic Fuzzy Sets (IFS) [1] as part of the MCDM, similarly, this fuzzy sets have generated hybridizations with some MCDM, as is the example of the MOORA method with IFS [2] which, for the transportation area and urban mobility allows hierarchigin the route alternatives and detect the route with the best characteristics for given criteria [3]. Thus, the assumptions of rating criteria according to the opinion in linguistic terms of experts in the subject, followed by a mathematical analysis in some matrix represented by fuzzy numbers to evaluate the alternatives and establish and hierarchical order [4]. In the last decade, new methods for assessing MCDM problems

31 have emerged as a response to include some characteristic which the actual methods not considered
32 [5] as the COmbinative Distance-based Assessment (CODAS) method developed by [6] that has the
33 goal of determine the which is the best alternative based on the Euclidean distance as the primary
34 measure and the Taxicab distance (or Manhattan) that is the secondary measure when the Euclidean
35 distances are incomparable.

36

37 1.1. *Multicriteria decision making*

38 In the last three decades, multicriteria decision making (MCDM) have been take on vital
39 importance in mathematics problems and computational sciences, their principal characteristic is the
40 valuation as applied science which has the objective of determine the value of something such as a
41 product or service, using elements of comparison where a professional evaluate all the criteria for
42 every alternative that usually is subjective and quantitative information [7]. [8] present two categories,
43 see , with the classification of the methods of multicriteria decision: first, the Multi-attribute Decision
44 Making (MADM) used to resolve discrete problems where the alternatives are predetermined and the
45 professional evaluate “a priori” every criteria, and the Multi-Objective Decision Making (MODM)
46 that is used to resolve continue problems where the alternatives are not predetermined and will have
47 some continue solutions respect of two or more criteria named Pareto’s border where the professional
48 participate a posteriori [9]. The MCDM usually are used to obtain the best alternative to fully satisfy
49 a range of indicate of performance [10] and are based on the criteria with best preferred aspects
50 according to the objectives of every problem or project, these criteria also are considered in a process
51 of evaluation.

52 In general, the MCDM consist in assign choice weights, analyze via pair-wise ranking of the
53 alternatives respect of a criterion and establish the importance and preference criteria or alternatives in
54 an evaluation’s matrix to homogenize because in the multicriteria decision making the information
55 can be qualitative data too, therefore suggest that the evaluation be with an objective vision where the
56 intuition of every decision maker (professional) represent their experience in individual evaluation
57 [3]. Also is describe as the process of the evaluation and selection of the best alternative of the
58 universe [11] because we can classify as necessary to reduce bias and expose the problem with precision.

59

Table 1. Multi-criteria decision methods and their approaches

Method	Author
SAW	[12]
COPRAS	[13]
TOPSIS	[14]
VIKOR	[15]
MAUT	[16]
MAVT	[17,18]
AHP	[19]
F-AHP	[20,21]
MACBETH	[22]
PROMETHEE	[23–25]
ELECTRE	[26]
WSM	[27]
WPM	[28]
SMART	[29]
SMARTER	[30]
MOORA	[4]
MULTIMOORA	[31]
WASPAS	[32]
MAUA	[33]
ARAS-F	[34]
KEMIRA	[35]
ARAS	[36]
SWARA	[37]
NAIADE	[38]
EDAS	[39]

60 Furthermore, there were different methods of multicriteria to solve problems of transport and
 61 urban mobility, also applied in urban planification and Geographic Information System (GIS) for select
 62 the best alternative in a project and to implement politics publics, because this is necessary to design
 63 indicators for monitoring it [40]. The principal MCDM are Analytic Hierarchy Process (AHP), Analytic
 64 Network Process (ANP), [41]; Multicriteria Optimization and Compromise Solution (compromiso
 65 (VIKOR, ViseKriterijumsa Optimizacija i Kompromisno Resenje); Preference Ranking Organization
 66 Method for Enrichment of Evaluations (PROMETHEE) [42]; Elimination and Choice Expressing Reality
 67 (ELECTRE); and Multi-Objective Optimization on the basis of the Ratio Analysis (MOORA) introduced
 68 by [4], among other relevant methods, see the synthesis in the **Table 1**.

69 Thus,[6] were the first to developed the combinative distancebased assessment (CODAS) method
 70 based into crisp sets or ordinal information to assessment some alternatives. This method is based on
 71 the combination of the Euclidean distance as the primary unit and the Taxicab (or Hamming) distance
 72 as the secondary unit to compared between them respect to the negative-ideal point; Ghorabae applied
 73 CODAS method to select a industrial robot using criterios of its operation. Also, [43] used linguistic
 74 variables and trapezoidal fuzzy numbers to extend the CODAS to evaluate market segmentation,
 75 they results were compare with ranking of Fuzzy EDAS and Fuzzy TOPSIS methods for the same
 76 problem. [44] proposed an integration of the multi-criteria decision making to solve problems about
 77 maintenances for industrial process, therefore to calculate the weights of criteria and subcriteria is
 78 used Geometric Mean (GM) method, then the weights calculated are include in the proposed method
 79 to rank the alternatives of the strategy maintenance.
 80 Thereby,[45] applied CODAS methods using crisp sets in a case study of supplier selection for a
 81 steelmaking company in Libya. They used sensivity analysis to measure the validaty and stability
 82 of this method. Time after, [46], developed an integration of the CODAS method using Pythagorean
 83 fuzzy sets and applying the proposal to select a supplier in a manufacturing firm.[47] introduced
 84 an application with WDBA to select the optimum alternative with CODAS method, the principal
 85 characteristic that provided WDBA is to compare the shortest distance with the negative-ideal solution.
 86 [48] developed a problema to select the best location to install a desalination plant using the geographic

87 information of Libya as criteria. [49] evaluated model of business intelligence for enterprise system,
 88 the model consist in fuzzy numbers to calculate criteria weights and to evaluate alternatives with
 89 intuitionistic fuzzy logic with interval values.
 90 [50] used the pairwise to determine the importance level of the criteria and, then the method integrate
 91 CODAS crisp to select wave energy technology as a case of study. IVIF-CODAS method was used
 92 by [51] to select sustainable material in construction projects with incomplete weight information,
 93 Roy developed a sensitivity analysis to validate IVIF-CODAS changing weights of criteria reaching a
 94 high degree of stability. [52] developed a case study for personnel selection with linguistic terms of
 95 uncertainty (Hesitant Fuzzy Linguistic Term Sets, HFLTS); in a similar case of application using this
 96 information type [53] appraise organizational and technological into industry 4.0.
 97 In a different view of application [54] used SWARA as tool to calculate criteria weights and CODAS
 98 under crisp sets to select material for dam construction based on the technical specifications (chemical
 99 and physics) of each alternative. [55] are very recognized to developed and worked with multi-criteria
 100 decision making, they developed a model of decision making based in CODAS under intuitionistic
 101 fuzzy to determine and prioritize strategies of SCL (Smart City Logistic). [56] assess the performance of
 102 bank institutions using entropy method to calculate weights criteria and CODAS to assess the stability
 103 and level of performance. Also, Ouhibi and Moalla proposed multiple classification and categories
 104 under incremental positions for central profiles and limits used to compare the distances of the
 105 CODAS method. [57] work with a method to select the best alternative to install wind generation
 106 plants.
 107 Using the best and worst (BWM) method, [58] evaluated the weights of the criteria and the linguistic
 108 variables with 2-tuple interval values. To select computer system to work in the cloud according
 109 to criteria of availability, reliability, security, maintenance, among others [59] developed a special
 110 application using Interval-Valued Intuitionistic Fuzzy CODAS for Multiattribute Decision-Making
 111 Method in Tehran. In another order of ideas, [5] which performed a comparison of MOORA with
 112 CODAS methods under Pythagorean Fuzzy Sets to show the benefits and disadvantages between
 113 this methods. Flores Ruvalcaba found that weight of the criteria in CODAS method just considers
 114 necessary one expert to apply the method through linguistic terms does not have a step for calculate
 115 the contribution of the stakeholders, this is stakeholders are named Decision Makers (DM) in MCDM.
 116 [60] developed an interesting model of aggregation with pythagorean fuzzy sets with CODAS and pure
 117 linguistic information with application to financial strategies of multi-national companies.

118 1.2. Weights of the criteria and decision makers

119 The contributions of criteria in multi-criteria decision making is expressed through the integration
 120 of the DM's opinions. [2] use the Intuitionistic Fuzzy Weighted Average (IFWA) for rating the k th
 121 DM, then [61] change the information type using Pythagorean Fuzzy Set (PFS) instead of Intuitionistic
 122 Fuzzy Set (IFS), therefore they used the same configuration, named as fuzzy weighted arithmetic
 123 Pythagorean, that is based on the geometry like Pythagorean fuzzy weighted arithmetic averaging
 124 (PFWAA) operator, this operator can be used with PFS because is an extension of IFS [62] and can
 125 provide better certainty to reduce uncertainty.

Table 2. Pythagorean Fuzzy Numbers of the criteria and DMs

Criteria Term	Symbol	μ	ν
Very Unimportant	VU	0.10	0.90
Unimportant	U	0.35	0.60
Medium	M	0.50	0.45
Important	I	0.75	0.40
Very Important	VI	0.90	0.10

126 Entropy is another method that works on a predefined decision matrix of criteria. The concept of
 127 entropy has two sides, first, when the concept refers to a measure of a certain property of a system

128 like a temperature; second, when the concept is subjective and can be used as a tool to build models
 129 [63]. This method can be combined with MCDM to evaluate alternatives though the weight of the
 130 criteria because all criteria do not have same degree of importance in decision-making in real life.
 131 The entropy method of the set of normalized outcomes of the j th criterion is given by the degree of
 132 diversity of the information.

133 1.2.1. The criteria for public transportation

134 The criteria for public transportation are based in their contribution of the operation's performance
 135 and the quality of the service. Also, the COVID-19 pandemic that appears in Wuhan, China on
 136 December 2019 [64], then covered Mexico on March 2020 influences in the service and operation due
 137 to the interaction of different mass of people inside buses throughout the day because the COVID-19 is
 138 highly deadly and and contagious through contact with body fluids [65]. Thus, the risk conditions are
 139 increase due to the lack of sanitation protocols, the use of face masks, and healthy distance between
 140 users as minimum of 6 feets as recommend the World Health Organization (WHO) [66].

Table 3. The decision criteria

Criteria	Reference
Average travel time, Convenience, Security, Reliability, Flexibility, Precision, Operational risk, Quality of service, Energy consumption, Available, Accessibility	[67]
Timeliness, Average travel time, Convenience, Intramodality, Security, cost, System coverage, Service timetable, Reliability, Velocity, Comfortable, Available, Mobility impact	[10]
Frequency, Security, Cost, Comfortable and Accessibility	[68]
Timeliness, Average travel time, Cost, System coverage	[42]
Cost, Occupancy, Comfortable, Accessibility, Information	[69]
Visual information of COVID-19 of mask, Training protocols of COVID-19, identify safe seats	[66]

141 2. Basic concepts of Pythagorean Fuzzy Set

142 In this section, we described some basic concepts of PFSs, introduced by Yager are explained as
 143 follows.

144 A Pythagorean fuzzy set give the characteristic of the membership and non-membership degrees that
 145 must be equal or less than 1, and that is the principal difference with Intuitionistic Fuzzy Sets (IFS)
 146 introduced by Atanassoc in 1986 because in IFS the contribution or membership and non-membership
 147 degrees in general are more than 1.

148 Definition 1. Let a set X be a universe of discourse. A PFS P is represented as the next form equation:
 149 $\tilde{P} = \{ \langle x, P(\mu_P(x), \nu_P(x)) \rangle \mid x \in X \}$ Here $\mu_{P(x)}$ and $\nu_{P(x)} \in X \rightarrow [0, 1]$ depict the degree of membership
 150 and non-membership function of the fuzzy set P ; $\mu_{P(x)} \in [0, 1]$ depict the membership degree of
 151 $x \in X$ in P . For all PFS it is necessary the next condition:

152

$$(\mu_P(x))^2 + (\nu_P(x))^2 \leq 1$$

153 Also, the degree of hesitancy that is called indeterminacy grade or Pythagorean index degree, $\pi_P(y)$,
 154 of x in P can be calculate as follows:

$$\pi_P(y) = \sqrt{1 - ((\mu_P(x))^2 + (\nu_P(x))^2)}$$

155 Where $(\mu_P(x))^2 + (\nu_P(x))^2 \leq 1$ is for each $x \in X$.

156 Definition 2. Consider two PFNs [60] as $\tilde{P}_1 = \{ \langle x, P_1(\mu_{P1}(x), \nu_{P1}(x)) \rangle \mid x \in X \}$ and $\tilde{P}_2 =$
 157 $\{ \langle x, P_2(\mu_{P2}(x), \nu_{P2}(x)) \rangle \mid x \in X \}$ the following basic operations are valid:

158

$$\tilde{P}_i = (\mu_{P_i}, \nu_{P_i})$$

$$\tilde{P}_1 \oplus \tilde{P}_2 = \left(\sqrt{1 - (1 - \mu_{P1}^2)(1 - \mu_{P2}^2)}, \nu_{P1} \cdot \nu_{P2} \right)$$

$$\tilde{P}_1 \otimes \tilde{P}_2 = \mu_{P1} \cdot \mu_{P2}, \sqrt{1 - (1 - \nu_{P1}^2)(1 - \nu_{P2}^2)}$$

$$\lambda \tilde{P} = P \left(\sqrt{1 - (1 - \mu_P^2)^\lambda}, (\nu_P)^\lambda \right), \lambda \geq 0 \text{ and } \lambda \in R$$

Table 4. Pythagorean Fuzzy Numbers of the alternatives

Alternative Term	Alternative Symbol	μ	ν	π
Extremenly Low	EL	0.10	0.99	0.10
Very Low	VL	0.10	0.97	0.22
Low	L	0.25	0.92	0.30
Medium Low	ML	0.40	0.87	0.29
Medium	M	0.50	0.80	0.33
Medium High	MH	0.60	0.71	0.37
High	H	0.70	0.60	0.39
Very High	VH	0.80	0.44	0.41
Extremenly High	EH	1	0	0

159 **3. The proposed methodology**

160 This section describes the method proposed for CODAS with multi-criteria decision-making and
 161 Pythagorean Fuzzy Sets, following the methodology show in Figure 1.

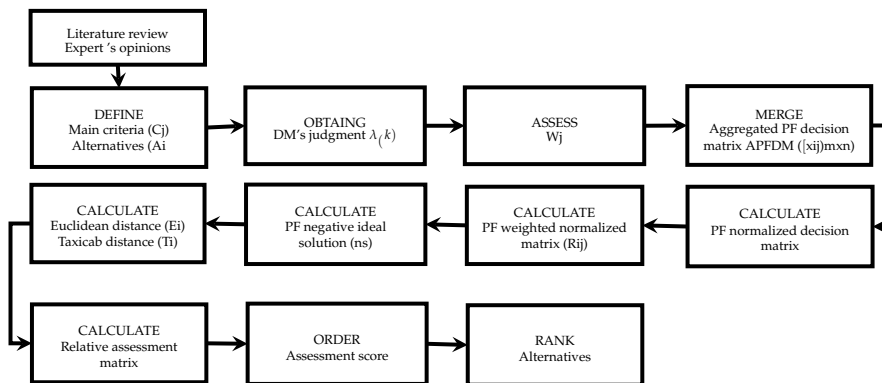


Figure 1. PF-CODAS Methodology (Source: The authors)

162 In addition, the major contribution is the way of calculate the Pythagorean Fuzzy weight
 163 of criteria and the contribution of the expertise of the Decision Makers (DMs) for evaluate every
 164 alternative; also it can see how to select the best threshold parameter "tau" to analyze the distances
 165 Euclidean and Taxicab for two alternatives in the next steps.

166

167 **Step 1.** Define criteria and alternatives. Decision criteria are the group of criteria that can be
 168 describe the best way of performance of an alternative. The alternatives of set A_i with $i=1, 2, \dots, m$
 169 each of them evaluated for decision criteria of set C_j with $j=1, 2, \dots, n$.

170
 171 **Step 2.** Integrate a group of DMs to assess the group of decision criteria representative of the
 172 alternatives.

173 Where $DM = DM_1, DM_2, \dots, DM_k, \dots, DM_l$ is a set of Decision Makers. The expertise for each DM
 174 is established using linguistic terms expressed by pythagorean fuzzy numbers shown in **Table 2**. The
 175 overall contribution of every Decision Maker defined as $DM_k = \{\pi_k, \nu_k, \mu_k\}$ with the corresponding
 176 weight of k th DM is calculate using the concept proposed by Boran [61]:
 177

$$\lambda_k = \frac{\left(\mu_k + \pi_k \left(\frac{\mu_k}{\mu_k + \pi_k}\right)\right)}{\sum_{k=1}^l \left(\mu_k + \pi_k \left(\frac{\mu_k}{\mu_k + \pi_k}\right)\right)} \quad (1)$$

178 Where $\sum_{k=1}^l \lambda_k = 1$

179 **Step 3.** Determine the importance of criteria. Using the using linguistic terms expressed by
 180 pythagorean fuzzy numbers shown in **Table 4** the group of DMs analyze the criteria that describe all
 181 alternatives, then every DMs give an evaluation for each criteria to be considered and determine what
 182 is the contribution of each one to the problem.

183 Construct the matrix of asses for each criterion by k th DMs.

184

$$\tilde{w}_j = PFWA = \left(\tilde{w}_j^{(1)}, \tilde{w}_j^{(2)}, \dots, \tilde{w}_j^{(k)}\right) \quad (2)$$

$$\tilde{w}_j = \lambda_1 \cdot \tilde{w}_j^{(1)} \oplus \lambda_2 \cdot \tilde{w}_j^{(2)} \oplus \dots \oplus \lambda_k \cdot \tilde{w}_j^{(k)} \quad (3)$$

$$\tilde{w}_j = \left(\sqrt{1 - \prod_{j=1}^l (1 - \mu_{ij}^2)^{\lambda_k}}, \prod_{j=1}^l (v_{ij})^{\lambda_k}\right) \quad (4)$$

$$\tilde{w}_j = \frac{\left(\mu_k + \pi_k \left(\frac{\mu_k}{\mu_k + \pi_k}\right)\right)}{\sum_{k=1}^l \left(\mu_k + \pi_k \left(\frac{\mu_k}{\mu_k + \pi_k}\right)\right)} \quad (5)$$

185 **Step 4.** Construct the Pythagorean fuzzy decision matrix for alternative assessment is given in
 186 the following equation:

187 The individual opinion of DM in linguistic terms are transformed using the linguistic variables of the
 188 **Table 4**, then all opinions of each DM are included into an aggregated pythagorean fuzzy decision
 189 matrix (APFDM) as follows:

190

191 Where $\tilde{x}_{ij} \geq 0$ and $\tilde{x}_{ij} = (\mu_p, \nu_p)$ and $0 \leq (\mu_p(x))^2 + (\nu_p(x))^2 \leq 1$

$$\tilde{x}_{ij} = APFDM \left(\tilde{x}_{ij}^{(1)}, \tilde{x}_{ij}^{(2)}, \dots, \tilde{x}_{ij}^{(k)}\right) \quad (6)$$

$$\tilde{x}_{ij} = \lambda_1 \cdot \tilde{x}_{ij}^{(1)} \oplus \lambda_2 \cdot \tilde{x}_{ij}^{(2)} \oplus \dots \oplus \lambda_k \cdot \tilde{x}_{ij}^{(k)} \quad (7)$$

$$\tilde{x}_{ij} = \left(\sqrt{1 - \prod_{j=1}^l (1 - \mu_{ij}^2)^{\lambda_k}}, \prod_{j=1}^l (v_{ij})^{\lambda_k}\right) \quad (8)$$

Then, the APFDM is defined as:

$$\tilde{X} = [x_{ij}]_{m.n} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \quad (9)$$

192 **Step 5.** Calculate the Pythagorean fuzzy normalized matrix using linear normalization as in the
193 following equation

$$\eta_{\mu_{ij}} = \frac{\tilde{x}_{ij}}{\max_i \tilde{x}_{ij}}, \eta_{\nu_{ij}} = \frac{\min_i \tilde{x}_{ij}}{\tilde{x}_{ij}} \quad \text{if } j \in N_b \quad (10)$$

$$\eta_{\mu_{ij}} = \frac{\min_i \tilde{x}_{ij}}{x_{ij}}, \eta_{\nu_{ij}} = \frac{\tilde{x}_{ij}}{\max_i x_{ij}} \quad \text{if } j \in N_c \quad (11)$$

194 where N_b and N_c represent the sets of benefit and cost criteria, respectively.

195 **Step 6.** Calculate the Pythagorean fuzzy weighted normalized matrix called \tilde{R}_{ij}

$$\tilde{R}_{ij} = \{\tilde{r}_{ij}\} = \tilde{w}_j \otimes \tilde{x}_{ij} \quad (12)$$

$$\tilde{R}_{ij} = \left\{ \left\langle x, \sqrt{1 - (\mu_{\tilde{x}_i}^2(x))^{w_j}}, \prod_{j=1}^l (\nu_{x_i}(x))^{w_j} \right\rangle x \in X \right\} \quad (13)$$

$$\tilde{R} = [x_{ij}]_{m.n} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \quad (14)$$

196 **Step 7.** Determine the Pythagorean fuzzy negative ideal solution as given in the following
197 equations:

$$\tilde{n}s = [\tilde{n}s_j]_{1 \times m} \quad (15)$$

$$\max_i \tilde{r}_{\mu_{ij}}, \min_i \tilde{r}_{\nu_{ij}} \quad \text{if } j \in N_b \quad (16)$$

$$\min_i \tilde{r}_{\nu_{ij}}, \max_i \tilde{r}_{\mu_{ij}} \quad \text{if } j \in N_c \quad (17)$$

198 **Step 8.** Calculate the Pythagorean fuzzy Euclidean and Taxicab distances of alternatives from the
199 negative ideal solution as the following equations:

$$E_i = \sqrt{\sum_{j=1}^m (\tilde{u}_{\mu_{ij}} - \tilde{n}s_{\mu_{ij}})^2 + (\tilde{u}_{\nu_{ij}} - \tilde{n}s_{\nu_{ij}})^2} \quad (18)$$

$$T_i = \sum_{j=1}^m |(\tilde{u}_{\mu_{ij}} - \tilde{n}s_{\mu_{ij}}) + (\tilde{u}_{\nu_{ij}} - \tilde{n}s_{\nu_{ij}})| \quad (19)$$

200 **Step 9.** Construct the relative assessment matrix based on the Pythagorean fuzzy Euclidean and
201 Taxicab distances as given in the following equations:

$$R_a = [h_{ik}]_{n \times n} \quad (20)$$

$$h_{ik} = (E_i - E_k) + (\psi(E_i - E_k) \times (T_i - T_k)) \quad (21)$$

202 where $k \in \{1, 2, \dots, n\}$ and c denotes a threshold function to recognize the equality of the Euclidean
 203 distances of two alternatives as given in the following equation:

204

$$\psi(x) = \begin{cases} 1 & \text{if } |x| \geq \tau \\ 0 & \text{if } |x| < \tau \end{cases} \quad (22)$$

205 If the difference between Euclidean distances of two alternatives is less than, these two alternatives
 206 are also compared by the Taxicab distance.

207 **Step 10.** Calculate the assessment score of each alternative as given in the following equation:

$$H_i = \sum_{k=1}^n h_{ik} \quad (23)$$

208 **Step 11.** Rank the alternatives according to the decreasing values of assessment score (H_i). The
 209 alternative with the highest H_i is the best alternative among the alternatives. In the Figure 3 can see
 210 that difference between Euclidean distances of two alternatives is less than, these two alternatives are
 211 also compared by the Taxicab distance.

212 4. Numerical case

213 This illustrative case belongs an assessment of public transportation system in Ciudad Juárez, in
 214 which several criteria described the principal characteristics that must have a good service to the users.
 215 **Step 1.** Define criteria and alternatives. The Table 3 contains the criteria and their explanation, it is very
 216 important consider the type of criteria this means that some criteria are of benefits (minimum values
 217 are ideal) and another are of cost (high values are ideal). In order to explain what the alternatives
 218 assessment in this proposal are, the modal distribution of public transportation system in Ciudad
 219 Juárez. Here, alternatives assessment in this proposal are described as follows in Table 5:

220

Table 5. Alternatives of public transportation

Line	Ramal	Status	Symbol
1-A	Paseo de la Victoria (Express)	In service	R1
1-A	Morelos	In service	R2
1-A	Unitec	In service	R3
1-A	Tradicional	In service	R4
1-B	Talamas (Express)	In service	R5
Universitaria	Universitaria	In service	R6

221 **Step 2.** Integrate a group of DMs to assess the group of decision criteria representative of the
 222 alternatives is shown in Table 6.

Table 6. The contribution of every Decision Makers

Decision Maker	1	2
Linguistic Term	D	Ap
PF number	{ 0.90, 0.10, 0.42}	{ 0.10, 0.90, 0.42}

223 **Step 3.** The importance of criteria is shown in Table 7.

Table 7. Alternatives of public transportation

Sym.	Name	Type	DM1	DM2	μ_k	ν_k	π_k	$W(\lambda_j)$
C1	Frequency	Benefit	VI	I	0.891	0.115	0.44	0.052
C2	Timeliness	Benefit	I	M	0.734	0.405	0.546	0.0441
C3	Average travel time	Cost	VI	I	0.891	0.115	0.44	0.052
C4	Convenience	Benefit	I	M	0.734	0.405	0.546	0.0441
C5	Intramodality	Benefit	M	VI	0.588	0.387	0.71	0.0413
C6	Security	Benefit	VI	M	0.884	0.116	0.452	0.0521
C7	Cost	Cost	VI	VI	0.9	0.1	0.424	0.0521
C8	System coverage	Benefit	M	M	0.5	0.45	0.74	0.0361
C9	Service timetable	Benefit	M	M	0.5	0.45	0.74	0.0361
C10	Reliability	Benefit	VI	VI	0.9	0.1	0.424	0.0521
C11	Velocity	Cost	VI	VI	0.9	0.1	0.424	0.0521
C12	Occupancy	Benefit	I	I	0.75	0.4	0.527	0.0444
C13	Flexibility	Benefit	M	M	0.5	0.45	0.74	0.0361
C14	Precision	Benefit	M	M	0.5	0.45	0.74	0.0361
C15	Operational risk	Cost	VI	VI	0.9	0.1	0.424	0.0521
C16	Comfortable	Benefit	I	I	0.75	0.4	0.527	0.0444
C17	Quality of service	Benefit	I	I	0.75	0.4	0.527	0.0444
C18	Energy consumption	Benefit	VI	VI	0.9	0.1	0.424	0.0521
C19	Mobility impact	Benefit	VI	VI	0.9	0.1	0.424	0.0521
C20	Disponible	Benefit	M	M	0.5	0.45	0.74	0.0361
C21	Accessibility	Benefit	VI	VI	0.9	0.1	0.424	0.0521
C22	Information in stations	Benefit	M	M	0.5	0.45	0.74	0.0361
C23	Visual information on buses	Benefit	VI	VI	0.9	0.1	0.424	0.0521
C24	Protocols of COVID-19	Benefit	M	M	0.5	0.45	0.74	0.0361
C25	Identify safe seats and place	Benefit	VI	VI	0.9	0.1	0.424	0.0521

224 **Step 4.** Construct the Pythagorean fuzzy decision matrix for alternative assessment, then calculate
 225 the aggregated pythagorean fuzzy decision matrix that which is in Table 8 using Linguistic Terms.

Table 8. The evaluations of criteria for each alternative

Criteria	R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6
C1	H	MH	MH	M	MH	VH	M	MH	H	H	MH	VH
C2	VL	L	L	L	VL	VL	M	ML	L	M	VL	M
C3	ML	M	ML	M	H	VH	L	M	VH	MH	H	VH
C4	MH	M	M	MH	MH	H	H	M	M	M	ML	MH
C5	M	MH	MH	M	L	L	ML	MH	M	M	L	M
C6	M	MH	H	ML	MH	ML	M	MH	H	ML	MH	ML
C7	H	H	H	H	H	ML	H	H	H	H	H	ML
C8	M	H	MH	MH	ML	M	M	H	H	M	ML	M
C9	M	ML	M	MH	ML	L	M	M	M	M	ML	L
C10	ML	M	MH	ML	ML	H	ML	M	MH	ML	ML	H
C11	L	H	M	MH	M	M	MH	H	MH	MH	VH	VH
C12	MH	M	M	L	MH	H	H	M	M	L	H	VH
C13	MH	L	VL	VL	VL	L	H	L	VL	M	L	L
C14	MH	H	M	MH	ML	L	MH	MH	M	H	ML	L
C15	VH	M	M	M	ML	MH	VH	M	H	M	M	H
C16	ML	M	ML	M	L	L	M	M	MH	M	L	M
C17	M	MH	M	ML	ML	ML	MH	MH	ML	M	MH	MH
C18	ML	MH	M	M	ML	M	ML	MH	M	M	ML	M
C19	H	H	H	H	MH	MH	MH	H	H	H	MH	MH
C20	ML	M	ML	H	ML	H	ML	M	ML	M	M	H
C21	L	MH	ML	MH	VL	L	M	MH	M	MH	VL	M
C22	VL	M	MH	ML	VH	VH	VL	M	M	ML	M	M
C23	ML	ML	ML	ML	L	M	ML	M	ML	M	M	M
C24	MH	M	M	ML	ML	MH	M	ML	ML	ML	ML	M
C25	EL	L	ML	L	L	VL	VL	M	L	L	L	ML

226 **Step 5.** The Pythagorean fuzzy normalized matrix using linear normalization is in Table 9a.

Table 9a. Pythagorean Fuzzy Normalized Matrix

	C1		C2		C3		C4		C5		C6		C7		C8		C9	
	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν	μ	ν
R1	0.857	0.713	0.668	0.953	1.000	1.000	0.885	0.874	0.819	0.880	0.714	0.750	0.571	0.690	0.714	0.750	0.845	0.898
R2	0.750	0.620	0.935	0.992	0.776	0.914	0.723	0.763	1.000	1.000	0.857	0.845	0.571	0.690	1.000	1.000	0.696	0.833
R3	0.765	0.630	0.867	0.986	0.813	0.929	0.723	0.763	0.986	0.988	1.000	1.000	0.571	0.690	0.874	0.859	0.845	0.898
R4	0.660	0.566	1.000	1.000	0.759	0.904	0.855	0.849	0.833	0.888	0.571	0.690	0.571	0.690	0.845	0.835	1.000	1.000
R5	0.750	0.620	0.347	0.935	0.555	0.686	0.846	0.842	0.417	0.772	0.857	0.845	0.571	0.690	0.571	0.690	0.676	0.826
R6	1.000	1.000	0.668	0.953	0.485	0.503	1.000	1.000	0.481	0.783	0.571	0.690	1.000	1.000	0.714	0.750	0.423	0.781

Table 12a. Pythagorean fuzzy Euclidean distance

	C1	C2	C3	C4	C5	C6	C7	C8	C9
R1	0.576	0.723	0.792	0.580	0.643	0.675	0.000	0.724	0.645
R2	0.653	0.523	0.009	0.693	0.000	0.575	0.000	0.000	0.733
R3	0.644	0.596	0.012	0.693	0.427	0.000	0.000	0.623	0.645
R4	0.706	0.000	0.007	0.606	0.633	0.751	0.000	0.646	0.000
R5	0.653	0.865	0.001	0.613	0.842	0.575	0.000	0.790	0.743
R6	0.001	0.723	0.001	0.000	0.815	0.751	0.751	0.724	0.849

Table 12b. Pythagorean fuzzy Euclidean distance

	C10	C11	C12	C13	C14	C15	C16	C17	C18
R1	0.751	0.810	0.601	0.000	0.628	0.001	0.629	0.606	0.702
R2	0.675	0.000	0.704	0.854	0.000	0.011	0.000	0.000	0.000
R3	0.575	0.002	0.704	0.942	0.720	0.007	0.605	0.632	0.595
R4	0.751	0.000	0.863	0.889	0.614	0.011	0.000	0.712	0.595
R5	0.751	0.001	0.601	0.929	0.787	0.778	0.801	0.698	0.702
R6	0.000	0.001	0.000	0.854	0.872	0.002	0.766	0.698	0.595

Table 12c. Pythagorean fuzzy Euclidean distance

	C19	C20	C21	C22	C23	C24	C25
R1	0.367	0.790	0.794	0.955	0.646	0.000	0.892
R2	0.000	0.724	0.000	0.761	0.630	0.597	0.657
R3	0.000	0.790	0.691	0.702	0.646	0.597	0.000
R4	0.000	0.477	0.000	0.815	0.630	0.697	0.714
R5	0.575	0.783	0.930	0.001	0.767	0.697	0.714
R6	0.575	0.000	0.794	0.001	0.000	0.000	0.892

Table 13a. Pythagorean fuzzy Taxicab distance

	C1	C2	C3	C4	C5	C6	C7	C8	C9
R1	0.748	0.850	0.890	0.756	0.797	0.818	0.017	0.848	0.799
R2	0.804	0.721	0.088	0.833	0.009	0.749	0.017	0.012	0.854
R3	0.798	0.770	0.105	0.833	0.644	0.017	0.017	0.782	0.799
R4	0.840	0.003	0.081	0.774	0.791	0.867	0.017	0.798	0.008
R5	0.804	0.930	0.002	0.779	0.917	0.749	0.017	0.889	0.860
R6	0.025	0.850	0.031	0.010	0.903	0.867	0.867	0.848	0.921

Table 13b. Pythagorean fuzzy Taxicab distance

	C10	C11	C12	C13	C14	C15	C16	C17	C18
R1	0.867	0.900	0.765	0.010	0.785	0.030	0.790	0.775	0.838
R2	0.818	0.018	0.834	0.923	0.013	0.103	0.005	0.008	0.009
R3	0.749	0.039	0.834	0.971	0.844	0.082	0.775	0.792	0.767
R4	0.867	0.009	0.929	0.942	0.775	0.103	0.005	0.844	0.767
R5	0.867	0.024	0.765	0.964	0.885	0.882	0.895	0.835	0.838
R6	0.017	0.024	0.018	0.923	0.934	0.037	0.875	0.835	0.767

Table 13c. Pythagorean fuzzy Taxicab distance

	C19	C20	C21	C22	C23	C24	C25
R1	0.599	0.889	0.888	0.977	0.802	0.009	0.944
R2	0.008	0.848	0.014	0.866	0.792	0.769	0.807
R3	0.008	0.889	0.826	0.829	0.802	0.769	0.006
R4	0.008	0.680	0.014	0.899	0.792	0.835	0.842
R5	0.758	0.885	0.964	0.023	0.876	0.835	0.842
R6	0.758	0.012	0.888	0.023	0.005	0.009	0.943

231 **Step 9.** Construct the relative assessment matrix based on the Pythagorean fuzzy Euclidean and
 232 Taxicab distances as the Table 14.

Table 14. Pythagorean fuzzy relative appraisal

Route	R1	R2	R3	R4	R5	R6
R1	0.000	0.845	0.370	0.478	-0.137	0.546
R2	-0.845	0.000	-0.476	-0.368	-0.982	-0.299
R3	-0.370	0.476	0.000	0.108	-0.507	0.176
R4	-0.478	0.368	-0.108	0.000	-0.615	0.068
R5	0.137	0.982	0.507	0.615	0.000	0.683
R6	-0.546	0.299	-0.176	-0.068	-0.683	0.000

233 **Step 10.** The assessment score of each alternative Table 15.

Table 15. Assessment score and rank

Route	Hi	RANK
R1	2.101	2
R2	-2.970	6
R3	-0.116	3
R4	-0.765	4
R5	2.925	1
R6	-1.175	5

234 5. Comparative analysis

235 In order to evaluate our proposal, some variations were carried out in the decision makers'
 236 contribution with different threshold functions as suggests [6]. This sensitivity analysis is performed
 237 to determine the consistency of the changes of the alternatives for three different variation as shown in
 238 Figure 2.

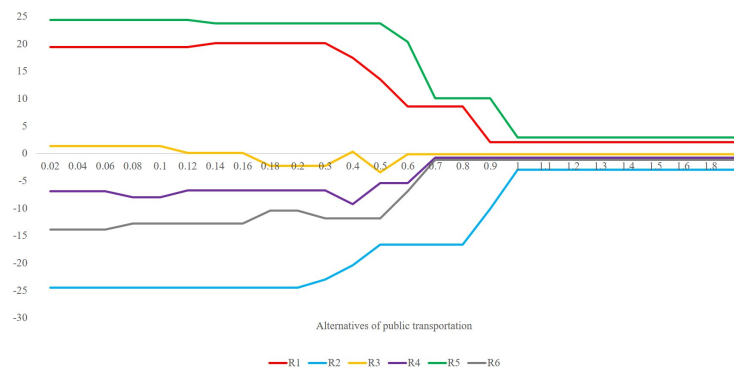


Figure 2. Sensitivity analysis of threshold function (Source: The authors)

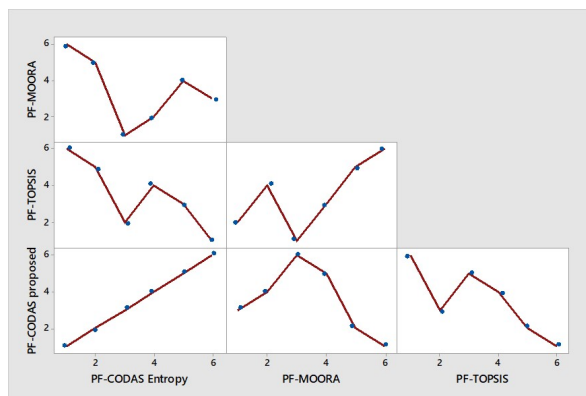
239 5.1. Comparative method

240 Different methods were compared with the proposed method of Pythagorean Fuzzy CODAS to
 241 observe how much is the influence of the Taxicab and Euclidean distance and the threshold function
 242 respect with PF-MOORA [61], PF-TOPSIS [70] and PF-CODAS proposed with a variant with entropy
 243 to criteria weights [71].

244

Table 16. Comparison with other methods

	PF-CODAS Entropy	PF-MOORA	PF-TOPSIS
PF-MOORA	-0.486		
PF-TOPSIS	-0.829	0.714	
PF-CODAS propose	1.000	-0.486	-0.829

**Figure 3.** Comparison methods (Source: The authors)

245 6. Conclusion.

246 This study is to propose an integrate method under Pythagorean Fuzzy with CODAS technique
 247 that include a method to determine the criteria weights based on the expertise of the Decision Makers
 248 to the problem of the public transportation system. As we shown, the contributions of the decision
 249 makers can change the results of public transportation routes (ramales) that need attentions. This
 250 method integrates the individual contribution weight of each DM and this experience is related to the
 251 evaluation of each expert on the weight of each criteria. As well as the experience contributes in the
 252 evaluation of the criteria for each public transportation routes (the alternatives). The proposed method
 253 has a good correlation with other Pythagorean methods as shown in Table 16 and Figure 3

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 255 R.R.L.; formal analysis, I.J.C.P.O.; investigation, S.N.A.D. and D.L.-D.; resources, L.P.-D.; writing—original draft
 256 preparation, L.P.-D. and D.L.-C.; writing—review and editing, L.P.-D. and S.N.A.D.; visualization, J.A.H.G.;
 257 supervision, R.R.L.

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446 **Sample Availability:** Samples of the compounds are available from the authors.

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