An Intelligent Neutrosophic Model for Evaluation Sustainable Housing Affordability

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Abstract

An increasingly pressing concern for city planners, housing affordability (HA) is fundamentally a political problem involving the redistribution of city resources. While attention to social policy was and is very important, this is often spatially absent. So, this paper proposed a framework to evaluate sustainable housing affordability (SHA). In this research, we present a method for multi-criteria decision-making (MCDM) issues by adapting the method for ordering preferences according to the degree to which a given solution is like the ideal one (TOPSIS). Experts' assessments of every choice in terms of each criterion are reflected in a single-valued neutrosophic set (SVNS). More gaps in knowledge may be filled in with the help of neutrosophic sets, which are differentiated by their truth, indeterminacy, and falsity values. The SHA is evaluated using the SVNS TOPSIS method. Lastly, an instance illustration is given to showcase the strategy's usefulness and efficacy.

Keywords: Single Valued Neutrosophic Set; MCDM; TOPSIS; Sustainable Housing Affordability; Evaluation

1. Introduction

In order to build sustainable communities and homes, it is crucial to address concerns of affordability at the same time. Households require reasonable quality cheap housing that is well placed inside high-quality settings that are neat, secure, and have excellent accessibility to employment, important services, and transit options in order to accomplish social and family welfare. Making ensuring that affordable accommodation is both sustainable for the ecosystem and fair for its residents is a matter of effectiveness and fairness[1], [1], [2].

Consequently, it may be necessary to enhance the availability of amenities, services, and the energy effectiveness of residential as a way to establish effective and sustainable living surroundings, in addition to addressing the price of residential in order to increase HA. However, conventional affordability indicators are unidimensional in that they continue to use monetary factors alone as a yardstick[3]–[5].

The issue of HA has been a hot topic of discussion throughout the world for a while now. The definition and quantification of HA, however, continue to be problematic and controversial. The monetary cost of housing

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expenditures is the primary focus of affordability assessments like the home price-to-income proportion method, the residual assessment (revenue left over after housing prices), and, since the effect of the most recent downturn, buy and payback affordability assessments. The proportional approach, which measures the percentage of income going towards housing expenditures, is the most often cited and globally known way of determining affordability. This makes sense, given that its simplicity and reliance on a small set of readily available parameters make it a computational dream[6]–[8].

However, its usefulness is constrained by its very simplicity, since it fails to account for a variety of variables that influence housing costs and family circumstances. The shortcomings of this conventional method are becoming more well-documented in the scientific literature. For example, the ratio metric does not take into account the fact that home prices might vary as a direct consequence of the perceived excellence of a community[9]–[11]. The SHA has various criteria like economic, social, environment, safety. So, this problem is a MCDM problem.

Operations studies, business administration, urban planning, the natural sciences, military history, etc. all benefit from tackling MCDM issues using quantitative or qualitative features values. Due to the complicated and unclear nature of attributes, the significance of MCDM issues' attributes is not usually stated with clear numbers. The importance of every characteristic and evaluation for various options are displayed in the form of crisp numbers in traditional MCDM approaches like the methodology for order preference by similarity to the ideal solution (TOPSIS) established by Hwang and Yoon[12], [13].

Zadeh's introduction of the fuzzy set is an example of a tool that makes use of mathematical imprecision. To represent the MCDM issue using fuzzy data, the fuzzy set theory may be used in the decision-making process. While useful, fuzzy sets are limited in their ability to capture nuanced relationships between variables and events[14], [15]. Non-member degrees and indeterminate degrees of uncertainty are not handled. Intuitionistic fuzzy sets (IFS) were first presented by Atanassov in 1986, and they combine levels of membership and non-membership[16], [17].

Neutrosophic sets (NS) were initially presented by philosopher Mihail Smarandache as a way to deal with the ambiguity and inconsistency of real-world data. Independently of one another, the truth, the indeterminacy, and the falsity characterize an NS. The fact that everything in the cosmos possesses not just a level of truth (T), but also of falsehood (F), and indeterminacy (I), is a crucial aspect of NS. The concepts of crisp set, FS, IVFS, IFS, IVIFS, etc. are all included in this more extended collection. However, the practical implementation of NS in engineering and science is challenging[18]–[20].

2. Preliminaries

The term "neutrosophic set" comes from the emerging field of neutrosophy, which examines the history of neutrality, its range of application, and the ways in which it interacts with other conceptual frameworks[21].

Definition 1

The complement of NS X can be defined as:

$$\begin{cases} T_X^m(y) = 1^+ \ominus T_X(y), \\ I_X^m(y) = 1^+ \ominus I_X(y), \\ F_X^m(y) = 1^+ \ominus F_X(y), \end{cases} \tag{1}$$

Definition 2

The total of 3 values of NS can be defined as:

$$0 \leq T(y) + I(y) + F(y) \leq 3 \tag{2}$$

Definition 3

Consider two number of single valued neutrosophic as a $C\ and\ D$, then

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$$C \oplus D = \begin{pmatrix} T_C(y) + T_D(y) - T_C(y) \cdot T_D(y), \\ I_C(y) \cdot I_D(y), \\ F_C(y) \cdot F_D(y) \end{pmatrix} \tag{3}$$

$$C \otimes D = \begin{pmatrix} T_C(y) \cdot T_D(y), \\ I_C(y) + I_D(y) - I_C(y) \cdot I_D(y), \\ F_C(y) + F_D(y) - F_C(y) \cdot F_D(y) \end{pmatrix} \tag{4}$$

$$C \cup D = \begin{pmatrix} \max\left(T_C(y), T_D(y)\right) \\ , \min\left(I_C(y), I_D(y)\right), \\ \min(F_C(y), F_D(y)) \end{pmatrix} \tag{5}$$

$$C \cap D = \begin{pmatrix} \min\left(T_C(y), T_D(y)\right) \\ , \max\left(I_C(y), I_D(y)\right), \\ \max(F_C(y), F_D(y)) \end{pmatrix} \tag{6}$$

3. Neutrosophic TOPSIS Method

The TOPSIS approach is employed to choose the optimal option from among the feasible compromises. If you want to find a good middle ground, look for a solution that minimizes the Euclidean distance between the ideal solution and the worst-case scenario and maximizes that distance. The group of options defined as: $SHAA_1 = \{SHAA_1, SHAA_2, \ldots.SHAA_m\}$ and $SHAC_1 = \{SHAC_1, SHAC_2, \ldots SHAC_n\}, i = 1,2,3, \ldots.m; j = 1,2,3, \ldots.n$ [21]. Figure 1 shows the steps of the TOPSIS method.

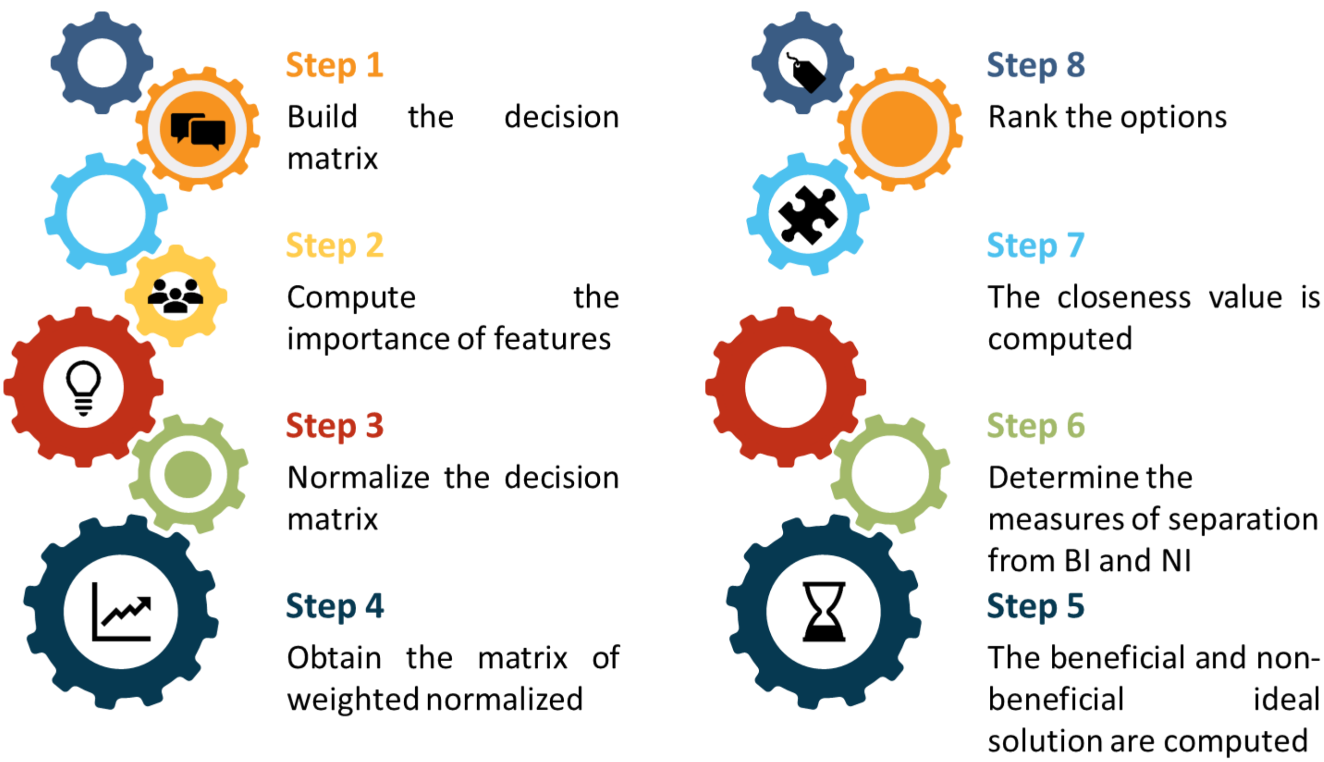

Figure 1: The stages of N-TOPSIS method.

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Stage 1. Build the decision matrix

The decision matrix is built by the decision makers and experts. The experts used the single valued neutrosophic scale to build the decision matrix. Then we replaced these terms by the single valued neutrosophic numbers[21].

Stage 2. Compute the importance of features

This step is used to compute the importance of criteria by the average TOPSIS method.

Stage 3. Normalize the decision matrix

This stage is used to normalize the decision matrix by identifying the positive and cost criteria.

$$P_{ij}^{N} = \frac{x_{ij}-P_j^{-}}{P_j^{+}-P_j^{-}} \text{ positive criteria} \quad (7)$$

$$P_{ij}^{N} = \frac{P_j^{-}-x_{ij}}{P_j^{+}-P_j^{-}} \text{ cost criteria} \quad (8)$$

$$\begin{pmatrix} P_j^{+} = \max_i p_{ij} \\ P_j^{-} = \min_i p_{ij} \end{pmatrix} \quad (9)$$

Stage 4. Obtain the matrix of weighted normalized

$$T_{ij} = w_j \times P_{ij}^{N} \quad (10)$$

Stage 5. The beneficial and non-beneficial ideal solution are computed

$$BI = \begin{Bmatrix} \left(\max_j T_{ij}\right), \\ \left(\min_j T_{ij}\right) \end{Bmatrix} \quad (11)$$

$$NI = \begin{Bmatrix} \left(\min_j T_{ij}\right), \\ \left(\max_j T_{ij}\right) \end{Bmatrix} \quad (12)$$

Stage 6. Determine the measures of separation from BI and NI

$$S_i^{+} = \sqrt{\sum_{j=1}^{n}\left(T_{ij} - T_j^{+}\right)^2} \quad (13)$$

$$S_i^{-} = \sqrt{\sum_{j=1}^{n}\left(T_{ij} - T_j^{-}\right)^2} \quad (14)$$

Stage 7. The closeness value is computed

$$L_i = \frac{S_i^{-}}{S_i^{+}+S_i^{-}} \quad (15)$$

Stage 8. Rank the options

4. Application

This section presented the application of single valued neutrosophic set TOPSIS method. We collated the criteria and alternative from the literature. Figure 2 shows the list of criteria. There are nine criteria are collated and ten options. First, let experts to evaluate the criteria and alternative to build the decision matrix as shown in Table 1.

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Table 1: The decision matrix

	$SHAC_1$	$SHAC_2$	$SHAC_3$	$SHAC_4$	$SHAC_5$	$SHAC_6$	$SHAC_7$	$SHAC_8$	$SHAC_9$
$SHA A_1$	(0.1,0.8, 0.9)	(0.2,0.7, 0.8)	(0.2,0.7, 0.8)	(0.7,0.3, 0.4)	(0.7,0.3, 0.4)	(0.8,0.2, 0.3)	(0.9,0.1, 0.2)	(0.6,0.4, 0.5)	(0.6,0.4, 0.5)
$SHA A_2$	(0.2,0.7, 0.8)	(0.7,0.3, 0.4)	(0.2,0.7, 0.8)	(0.2,0.7, 0.8)	(0.1,0.8, 0.9)	(0.4,0.5, 0.6)	(0.8,0.2, 0.3)	(0.8,0.2, 0.3)	(0.7,0.3, 0.4)
$SHA A_3$	(0.7,0.3, 0.4)	(0.9,0.1, 0.2)	(0.9,0.1, 0.2)	(0.7,0.3, 0.4)	(0.7,0.3, 0.4)	(0.4,0.5, 0.6)	(0.1,0.8, 0.9)	(0.9,0.1, 0.2)	(0.3,0.6, 0.7)
$SHA A_4$	(0.6,0.4, 0.5)	(0.4,0.5, 0.6)	(0.4,0.5, 0.6)	(0.4,0.5, 0.6)	(0.9,0.1, 0.2)	(0.1,0.8, 0.9)	(0.6,0.4, 0.5)	(0.4,0.5, 0.6)	(0.9,0.1, 0.2)
$SHA A_5$	(0.6,0.4, 0.5)	(0.9,0.1, 0.2)	(0.1,0.8, 0.9)	(0.2,0.7, 0.8)	(0.3,0.6, 0.7)	(0.6,0.4, 0.5)	(0.6,0.4, 0.5)	(0.7,0.3, 0.4)	(0.8,0.2, 0.3)
$SHA A_6$	(0.2,0.7, 0.8)	(0.7,0.3, 0.4)	(0.7,0.3, 0.4)	(0.7,0.3, 0.4)	(0.6,0.4, 0.5)	(0.9,0.1, 0.2)	(0.9,0.1, 0.2)	(0.9,0.1, 0.2)	(0.7,0.3, 0.4)
$SHA A_7$	(0.7,0.3, 0.4)	(0.7,0.3, 0.4)	(0.8,0.2, 0.3)	(0.7,0.3, 0.4)	(0.9,0.1, 0.2)	(0.4,0.5, 0.6)	(0.1,0.8, 0.9)	(0.2,0.7, 0.8)	(0.2,0.7, 0.8)
$SHA A_8$	(0.1,0.8, 0.9)	(0.4,0.5, 0.6)	(0.7,0.3, 0.4)	(0.7,0.3, 0.4)	(0.6,0.4, 0.5)	(0.7,0.3, 0.4)	(0.7,0.3, 0.4)	(0.7,0.3, 0.4)	(0.7,0.3, 0.4)
$SHA A_9$	(0.2,0.7, 0.8)	(0.4,0.5, 0.6)	(0.7,0.3, 0.4)	(0.9,0.1, 0.2)	(0.6,0.4, 0.5)	(0.6,0.4, 0.5)	(0.8,0.2, 0.3)	(0.6,0.4, 0.5)	(0.9,0.1, 0.2)
$SHA A_{10}$	(0.2,0.7, 0.8)	(0.7,0.3, 0.4)	(0.7,0.3, 0.4)	(0.6,0.4, 0.5)	(0.8,0.2, 0.3)	(0.7,0.3, 0.4)	(0.7,0.3, 0.4)	(0.8,0.2, 0.3)	(0.9,0.1, 0.2)

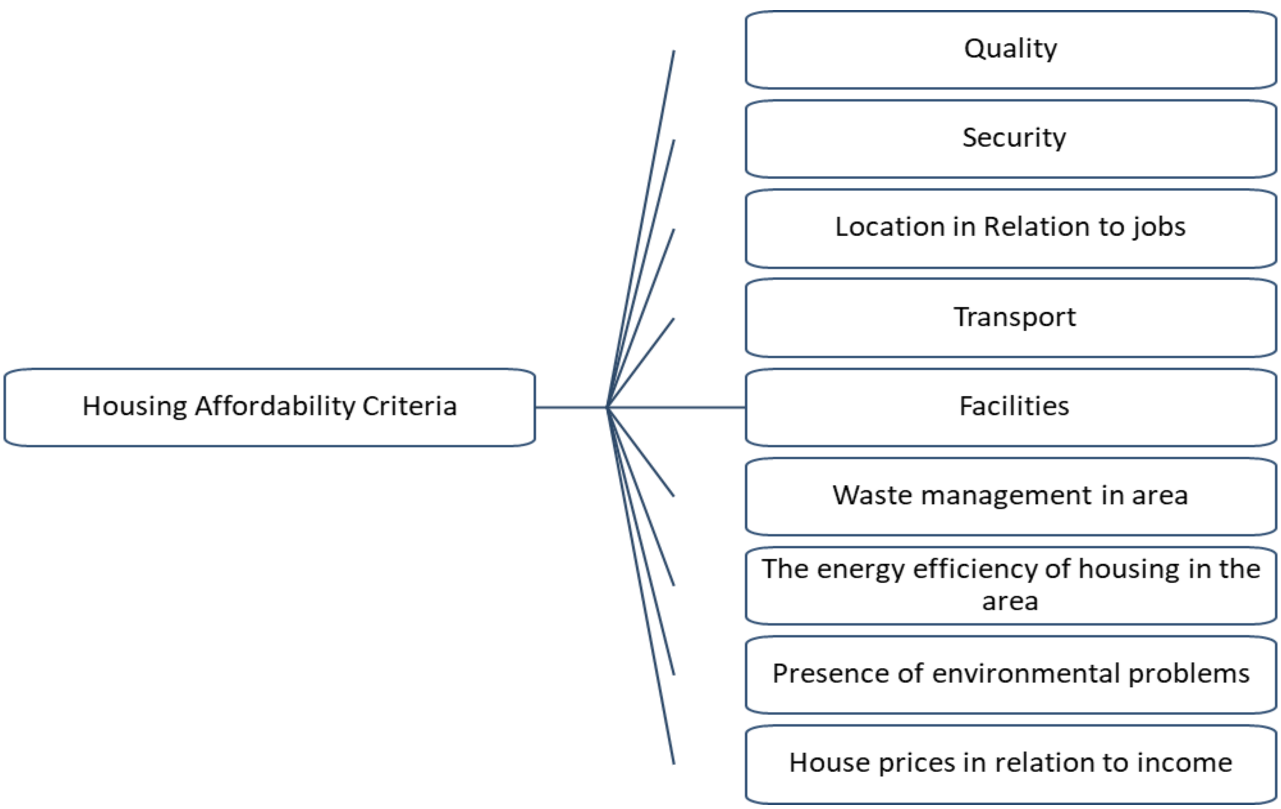

Figure 2: List of nine attributes.

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Then convert the opinions of experts by the single valued neutrosophic numbers[21]. Then compute the importance of attributes. The importance of attributes are shown in Figure 3.

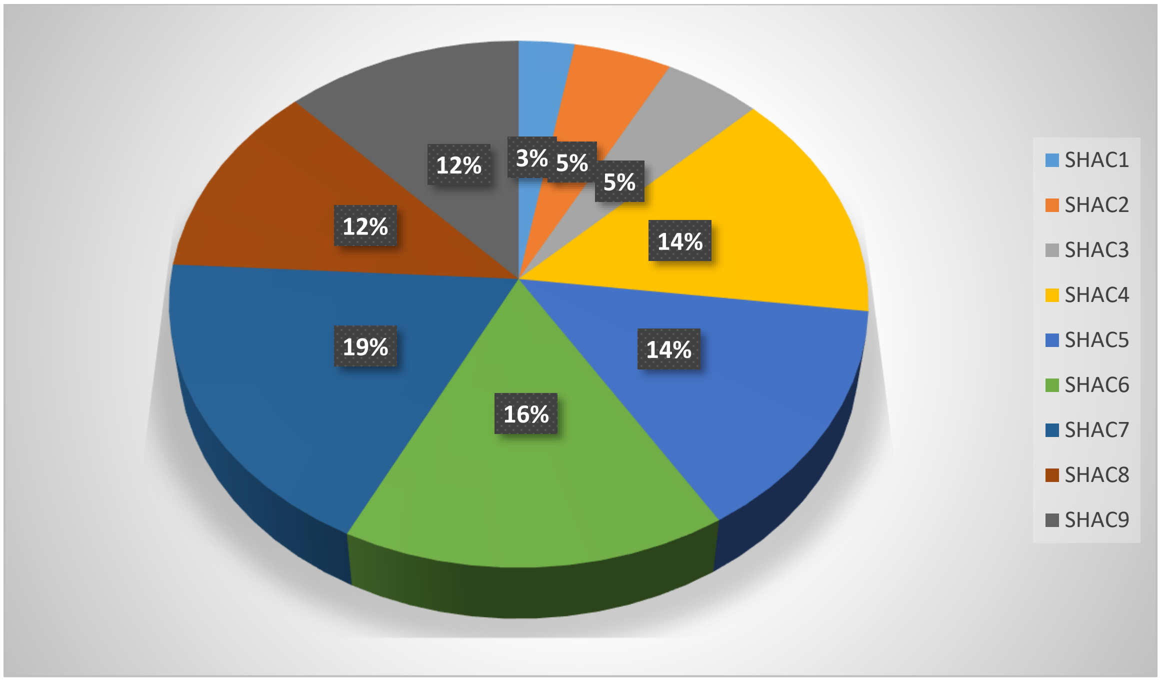

Figure 3: The importance of house affordability.

Then build the normalization matrix by using Eqs. (7,8,and 9). Then multiply the weights of criteria by the normalization matrix to obtain the weighted normalization matrix by using Eq. (10) as shown in Table 2.

Table 2: The weighted normalized decision matrix

	$SHAC_1$	$SHAC_2$	$SHAC_3$	$SHAC_4$	$SHAC_5$	$SHAC_6$	$SHAC_7$	$SHAC_8$	$SHAC_9$
$SHAA_1$	0.002832	0.005867	0.006254	0.049901	0.046867	0.067319	0.07757	0.032383	0.031646
$SHAA_2$	0.004955	0.016764	0.006254	0.017465	0.009373	0.03805	0.06862	0.043813	0.03723
$SHAA_3$	0.014158	0.021793	0.023228	0.049901	0.046867	0.03805	0.011934	0.049528	0.018615
$SHAA_4$	0.012034	0.010896	0.011614	0.032435	0.060927	0.011708	0.050719	0.024764	0.048399
$SHAA_5$	0.012034	0.021793	0.003574	0.017465	0.023433	0.049758	0.050719	0.038098	0.042815
$SHAA_6$	0.004955	0.016764	0.017868	0.049901	0.039837	0.0761	0.07757	0.049528	0.03723
$SHAA_7$	0.014158	0.016764	0.020548	0.049901	0.060927	0.03805	0.011934	0.013334	0.01303
$SHAA_8$	0.002832	0.009203	0.014158	0.014158	0.012034	0.014158	0.014158	0.014158	0.014158

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SHAA9	0.004955	0.009203	0.014158	0.018405	0.012034	0.012034	0.016282	0.012034	0.018405
SHAA10	0.004955	0.014158	0.014158	0.012034	0.016282	0.014158	0.014158	0.016282	0.018405

Then compute the positive and negative ideal solution by using Eqs. (11 and 12). Then compute the separation measures by using Eqs. (13 and 14). Then compute the closeness values by using Eq. (15). Then rank the alternatives by the largest value in closeness value. Figure 4 shows the closeness value and rank of alternatives.

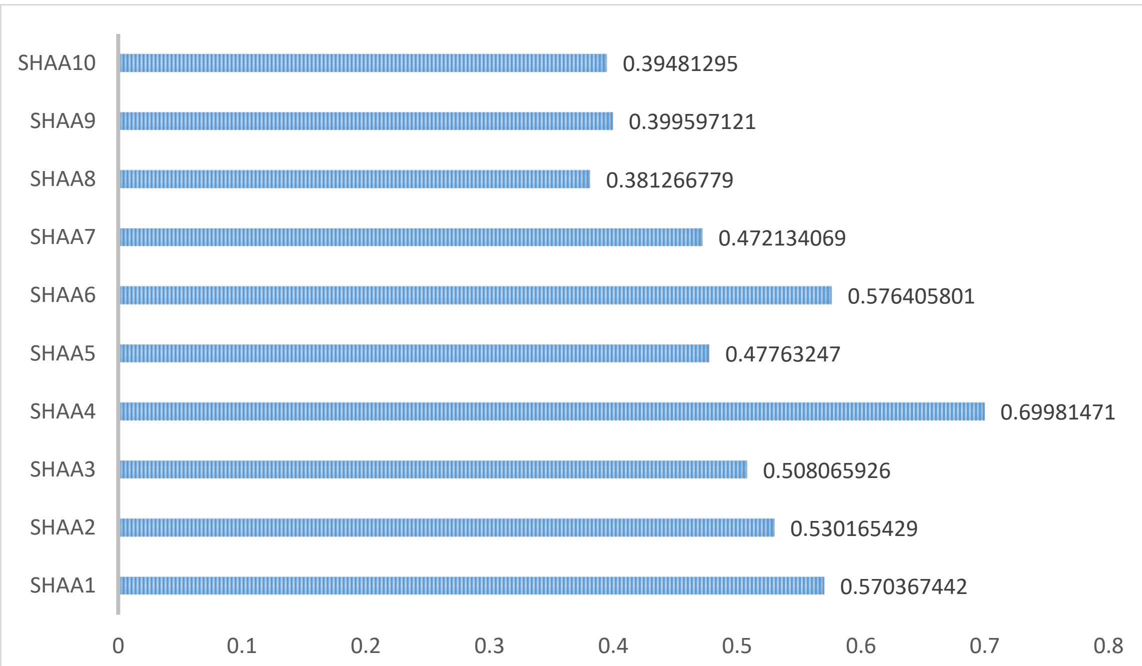

Figure 4: The closeness value of SHA.

5. Conclusion

To explain and quantify home affordability, rules regarding what is and is inappropriate must be established. Position in connection with careers, transportation, resources, and amenities has become a growing significance in the 2000s, especially in big cities, and must be taken into account when setting up standards for affordable, honest, and sufficient housing. The HA has multiple conflicting criteria like safety, location, social, resources, and others. So, this problem is an MCDM issue. But in the evaluation of these criteria, there are vague data, so the neutrosophic set is used to overcome this problem. The NS is integrated with the MCDM method to evaluate the HA criteria, then give important criteria for decision-makers and people. This paper used the TOPSIS method to rank the alternatives and give rank to the criteria. This study can aid the person in the HA.

In the future study, many criteria can be extended to this problem. Also, the fuzzy set can be applied to this problem and create a comparative analysis between the fuzzy set and neutrosophic set and give recommendations about two ranks. There are many MCDM methods like AHP, ANP, VIKOR, and MABAC methods that can be applied to this kind of problem.

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References

[1] E. Mulliner, N. Malys, and V. Maliene, "Comparative analysis of MCDM methods for the assessment of sustainable housing affordability," *Omega*, vol. 59, pp. 146–156, 2016.

[2] A. Valipour, H. Sarvari, and J. Tamošaitiene, "Risk assessment in PPP projects by applying different MCDM methods and comparative results analysis," *Adm. Sci.*, vol. 8, no. 4, p. 80, 2018.

[3] W. Cai and X. Lu, "Housing affordability: Beyond the income and price terms, using China as a case study," *Habitat Int.*, vol. 47, pp. 169–175, 2015.

[4] S. J. Newman and C. S. Holupka, "Housing affordability and child well-being," *Hous. Policy Debate*, vol. 25, no. 1, pp. 116–151, 2015.

[5] A. Acolin and R. K. Green, "Measuring housing affordability in São Paulo metropolitan region: Incorporating location," *Cities*, vol. 62, pp. 41–49, 2017.

[6] C. Zhang, S. Jia, and R. Yang, "Housing affordability and housing vacancy in China: The role of income inequality," *J. Hous. Econ.*, vol. 33, pp. 4–14, 2016.

[7] R. J. Bentley, D. Pevalin, E. Baker, K. Mason, A. Reeves, and A. Beer, "Housing affordability, tenure and mental health in Australia and the United Kingdom: a comparative panel analysis," *Hous. Stud.*, vol. 31, no. 2, pp. 208–222, 2016.

[8] K. Barron, E. Kung, and D. Proserpio, "The Sharing Economy and Housing Affordability: Evidence from Airbnb.," *EC*, vol. 5, 2018.

[9] E. Baker, R. Bentley, L. Lester, and A. Beer, "Housing affordability and residential mobility as drivers of locational inequality," *Appl. Geogr.*, vol. 72, pp. 65–75, 2016.

[10] M. Saberi, H. Wu, R. Amoh-Gyimah, J. Smith, and D. Arunachalam, "Measuring housing and transportation affordability: A case study of Melbourne, Australia," *J. Transp. Geogr.*, vol. 65, pp. 134–146, 2017.

[11] A. P. C. Chan and M. A. Adabre, "Bridging the gap between sustainable housing and affordable housing: The required critical success criteria (CSC)," *Build. Environ.*, vol. 151, pp. 112–125, 2019.

[12] R. M. Zulqarnain, X. L. Xin, M. Saqlain, F. Smarandache, and M. I. Ahamad, "An integrated model of neutrosophic TOPSIS with application in multi-criteria decision-making problem," *Neutrosophic Sets Syst.*, vol. 40, pp. 253–269, 2021.

[13] P. Biswas, S. Pramanik, and B. C. Giri, "Neutrosophic TOPSIS with group decision making," *fuzzy multi-criteria Decis. using neutrosophic sets*, pp. 543–585, 2019.

[14] X. Peng and J. Dai, "Approaches to single-valued neutrosophic MADM based on MABAC, TOPSIS and new similarity measure with score function," *Neural Comput. Appl.*, vol. 29, pp. 939–954, 2018.

[15] H. Garg, "A novel divergence measure and its based TOPSIS method for multi criteria decision-making under single-valued neutrosophic environment," *J. Intell. Fuzzy Syst.*, vol. 36, no. 1, pp. 101–115, 2019.

[16] M. Akram and F. Smarandache, "Decision-making with bipolar neutrosophic TOPSIS and bipolar neutrosophic ELECTRE-I," *Axioms*, vol. 7, no. 2, p. 33, 2018.

[17] P. Biswas, S. Pramanik, and B. C. Giri, "NonLinear programming approach for single-valued neutrosophic TOPSIS method," *New Math. Nat. Comput.*, vol. 15, no. 02, pp. 307–326, 2019.

[18] S. Nădăban and S. Dzitac, "Neutrosophic TOPSIS: a general view," in *2016 6th International Conference on Computers Communications and Control (ICCCC)*, Ieee, 2016, pp. 250–253.

[19] H. Sharma, A. Tandon, P. K. Kapur, and A. G. Aggarwal, "Ranking hotels using aspect ratings based sentiment classification and interval-valued neutrosophic TOPSIS," *Int. J. Syst. Assur. Eng. Manag.*, vol. 10,

Doi: https://doi.org/10.54216/IJAACI.020205
Received: June 12, 2022 Accepted: December 27, 2022

pp. 973–983, 2019.

[20] İ. Otay and C. Kahraman, “Six sigma project selection using interval neutrosophic TOPSIS,” in *Advances in Fuzzy Logic and Technology 2017: Proceedings of: EUSFLAT-2017–The 10th Conference of the European Society for Fuzzy Logic and Technology, September 11-15, 2017, Warsaw, Poland IWIFSGN’2017–The Sixteenth International Workshop on Intuitionistic*, Springer, 2018, pp. 83–93.

[21] P. Biswas, S. Pramanik, and B. C. Giri, “TOPSIS method for multi-attribute group decision-making under single-valued neutrosophic environment,” *Neural Comput. Appl.*, vol. 27, pp. 727–737, 2016.

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