Journal of Applied Research and Technology

www.jart.icat.unam.mx

Instituto de Ciencias Aplicadas y Tecnología

Journal of Applied Research and Technology 21 (2023) 56-72

Original

The preference selection index performance in large alternatives' decisions to support the AHP: The case of a university selection

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Received 01 29 2021; accepted 03 30 2022
Available 02 28 2023

Abstract: Two multi-criteria decision-making approaches were implemented in this paper for selecting a U.S. university considering the industrial engineering doctorate as a case study. These approaches were the Preference Selection Index (PSI) and the Analytical Hierarchy Process (AHP). A total of 37 universities and 20 attributes were considered. The attributes were related to the university's reputation, location, finances, and ease of admission. In this paper, the PSI model was initially constructed and its results were adopted in the AHP model. Data for this paper were obtained from the US News and World Report, Times Higher Education (THE), and other well-known organizations. Results proved that the PSI approach could be used in decisions with a large number of alternatives and attributes, and the PSI model was able in making the AHP model requirements easier, by reducing the criteria and alternatives. In both the PSI and the AHP models, the university's reputation had the highest preferences of students, followed by the ease of admission, finances, and then location. Sensitivity analyses for the PSI and AHP models were performed to evaluate the accuracy of the results. The results of this study could be applied to other students' disciplines for finding a suitable university.

Keywords: Multi-criteria decision making, preference selection index, analytical hierarchy process, graduate program admission, sensitivity analysis, industrial engineering

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Peer Review under the responsibility of Universidad Nacional Autónoma de México.

1. Introduction

Selection of n a university for a higeducationonal degree is one of the critical challenges that are faced by students, as it has significant consequences that affect students' careers. Many factors are of this decision concern, resulting in making this problem one of the multi-criteria decision-making (MCDM) problems. These criteria include but are not limited to financial, location, academic reputation, travel, immigration, and admission requirements. These attributes may internally include sub-criteria, for example, the financial criterion includes all attributes related to budget such as living expenses, tuition fees, financial assistance, etc.

Several criteria are considered in the problem of selecting a higher education facility, which makes it a non-intuitive decision. Several researchers have studied some of the considered factors that are related to university selection. However, most of these studies focused on helping undergraduate students select a university for an undergraduate degree.

This paper has several objectives. It evaluates the performance of the PSI in dealing with decision problems of a large number of alternatives and attributes. In addition, the paper helps international students select an appropriate university for studying for a doctorate in the U.S., by taking the industrial engineering discipline as a case study. The results of the PSI model of this study will help reduce the effort that is usually associated with building an AHP model, by starting the AHP model from the outcomes of the PSI model. In addition, this paper adds to the previous literature, in that there is no existing research found using either the AHP or PSI approaches for selecting a suitable university to study a doctorate in the U.S. majoring in industrial engineering.

2. Literature review

Bin Yusof et al. (2008) performed a study in Malaysia using stepwise regression analysis. In their model, the dependent variable was the preference for a specific university while the independent variables included the financial factors, location, industry expectations, facilities, and promotional factors. Based on the analysis of variance (ANOVA), the significant variables were the financial factors, industry expectations, and location. Their model was useful for higher education sector marketing, which focused on the parents' and students' important needs when choosing a university (Bin Yusof et al., 2008). Another study was also conducted in Malaysia, to examine factors related to choosing a university for undergraduate engineering students, along with determining the important factors of preference when choosing an engineering discipline (Misran, et al., 2012). The study considered questionnaires as a research methodology in addition to statistical analysis. They found that suitability, interest, and career opportunity were the most important considerations when selecting a university and an engineering discipline.

A study was conducted in Canada to evaluate the criteria considered by undergraduate business students in selecting a suitable university (Fuller & Delorey, 2016). Four different institutions were considered in this study, in-province and out-province students of the two gender participated in the study. The multivariate analysis of variance (MANOVA) was used in the data analysis. They found that a contingency-based approach to admissions and recruitment strategies of the recruitment officials and the university administration might help boost undergraduate enrollment rates. Shammot (2011) performed a study in Jordan for selecting a private university for the undergraduate program. Results show that for both females and males who participated, the financial cost was the main driving factor in selecting a university. For females, the reputation of the university was the most dominant factor in selecting a private university (Shammot, 2011).

The decision of selecting a university for pursuing a doctorate in the U.S. is very complicated, especially for students who need an entry visa. The MCDM techniques simplify the process of decision-making when multiple alternatives are available. MCDM tools follow a structural approach that involves defining all related attributes (criteria) then deciding the most important (weight) of each criterion to select the best alternative. In addition, MCDM techniques increase the insight of the person and simplify the complicated decision process (Govindan et al., 2015). There are many MCDM techniques including but not limited to Weighted Sum Method, Weighted Product method, Analytical Hierarchy Process (AHP), Elimination and Choice Expressing Reality (ELECTRE), Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS), Analytical Network Process (ANP), Preference Selection Index (PSI) and Multi Attribute Utility Theory (MAUT).

The PSI approach is a modern MCDM approach, it is a logical and novel quick approach that is used to find the best alternative from a group of alternatives without the need for assigning relative importance between attributes (Maniya & Bhatt, 2010). Several studies were conducted using the PSI method. Sawant et al. (2011) used the PSI method to select an automated guided vehicle. The results of their study showed that the PSI approach could be used as a validation tool to validate the results obtained by another MCDM approach (Sawant et al., 2011). Attri and Grover (2015) used the PSI for decisions in the design stage, where decisions sometimes are complicated because the designer has to compare between large numbers of alternatives. Comparing the results of the PSI approach with the results of other MCDM techniques, the PSI was found to obtain the same decision. Therefore, the PSI tool was proved as an accurate approach (Attri & Grover, 2015). The PSI approach was found as a useful approach in ranking water desalination technologies (Obeidat et al., 2021). The PSI is also implemented successfully in the selection of an educational scholarship recipient selectively (Mesran et al., 2017), in the selection of a cleaning method of solar panels (Obeidat et al., 2020) and many others.

The AHP approach has a wide range of applications in different fields (Mardani et al., 2015). The AHP reached decisions for complicated problems by quantifying certain attributes affecting the decision process, due to the non-numeric nature of these attributes; examples include ideas, emotions, feelings, etc. of people involved in the decision process (Taha, 2011). The AHP is a capable approach that determines the relative importance between criteria through pairwise comparisons and weighting alternatives (Saaty, 2008). The AHP was developed by Saaty (1987) and then used in versatile applications such as engineering, education, manufacturing, social, sport, and other personal decisions (Vaidya & Kumar, 2006). Vaidya and Kumar (2006) identified over than 150-application of AHP in 10 areas including allocation, selection, benefit-cost, evaluation, planning and development, priority and ranking, decision making, forecasting, quality function deployment, and medicine. Examples of AHP applications include the human critical life decisions in selecting an apartment (Obeidat et al., 2018), and selecting an electric vehicle (Al Theeb et al., 2019), in the field of supplier selection (Dweiri etal., 2016), cost-benefit analysis (Wedley et al., 2001), evaluation (Fan et al., 2016), allocation (Yu & Tsai, 2008), planning and development (Chen & Wang, 2010), priority and ranking (Khan & Ahmad, 2017; Kiruthika & Somasundaram, 2018), decision making (Özcan et al., 2011), generating electric power and make sustainable usage of productive soil (Tamayo & Arias, 2019), medicine (Moon, et al., 2015), forecasting (Wang et al., 2014), innovation in manufacturing (Blagojevic et al., 2019) and quality function deployment (Chen, 2016).

3. Methodology

In this study, two MCDM techniques were implemented for constructing a university selection model, to help students who are seeking admission to a doctorate program in the U.S decide upon a university. An industrial engineering doctorate program was considered as a case study. The selected MCDM techniques were the PSI and the AHP. The PSI model was initially constructed followed by the AHP model. Reasons for starting with the PSI were to highlight the highly significant attributes involved when selecting a university, evaluate the performance of 37 universities being considered in the U.S., and reduce both the attribute and alternatives number to make the AHP development easier. The outcomes of the PSI model have facilitated the process of constructing the AHP model with less number of both criteria and alternatives. This reduced the effort of building a complicated AHP model.

3.1. The PSI model

The PSI technique is relatively a new decisión-making approach (Maniya & Bhatt, 2010). It does not require comparing the attribute importance. For each alternative, a PSI value is computed, in which the best alternative is that of the highest PSI value. The PSI method is explained in this section (Maniya & Bhatt, 2010).

The first step of the PSI method is identifying the objective, determining all possible criteria, its measures, and alternatives. A total of 20 attributes were selected as shown in Table 1 for constructing the PSI model of this study. The attribute, which is the same as the criterion, is referred to by the letter ($\boldsymbol{C}$) as shown in Table 1. Selection of the attributes was based on the literature and on the results of interviewing a group of 65 industrial engineering students in Jordan seeking admission to a doctorate in industrial engineering in the U.S. Table 1 also classifies the attribute into a benefit or a cost.

Table 1. The considered attributes in the PSI model.

Attribute number	Attribute definition	Attribute type
C_1	Tuition expenses: University fees for international-full time doctoral students based on the US News Ranking website	Cost
C_2	Living and dining expenses: Room and boarding costs based on the Times Higher Education World's university rankings (THE) website	Cost
C_3	Scholarship opportunity: The easiness of achieving a scholarship based on Crunch Prep	Benefit
C_4	The opportunity for hunting a part-time job based on Crunch Prep	Benefit
C_5	The university is prestigious, which was measured according to the US News ranking for the industrial engineering program. Top-ranked universities were of a higher score; therefore, this is a beneficial attribute	Benefit

C_6	Facility resources, which are based on the Times Higher Education World's university rankings	Benefit
C_7	Research focus, which is provided by the Times Higher Education World's university ranking for engineering schools	Benefit
C_8	Diversity, which is based on Niche	Benefit
C_9	Weather status, which is obtained from several weather websites	Benefit
C_{10}	The beauty of the campus location: The U.S. states rank by its beauty, which is obtained from THRILLIST TRAVEL. Top-ranked states were given a higher score; therefore, this is a benefit attribute	Benefit
C_{11}	Campus safety, which is obtained from HomeSnack Rankings. Top-ranked states were given a higher score; therefore, this is a benefit attribute	Benefit
C_{12}	Racism, which is provided by New America. Top-ranked states mean bad location; therefore, this is a cost attribute	Cost
C_{13}	Admission rate, which is provided by the US News Rankings	Benefit
C_{14}	Undergraduate Grade Point Average (GPA) average for the admitted Ph.D. student, which is obtained from the U.S. News	Cost
C_{15}	English proficiency minimum required score. This is related to the Test Of English as a Foreign Language (TOEFL) score required by each university	Cost
C_{16}	The required Graduate Record Examination (GRE) verbal score based on the US News	Cost
C_{17}	The required GRE quantitative score based on the US News	Cost
C_{18}	The required GRE analytical writing score is based on the US News	Cost
C_{19}	Sports score based on Niche	Benefit
C_{20}	Employment rate based on Niche	Benefit

The second step in the PSI approach in formulating the decision matrix (X_{ij}). An example of the decision matrix is shown in Table 2. Let A be a set of alternatives, where A= {A_i for i= 1, 2, 3, …, n}, C be a set of decision criteria where C= {C_j for j = 1, 2, 3, …, m} and X_{ij} is the performance of alternative A_i when it is evaluated by criteria C_j. A total of 37 alternatives (universities) were considered. The selection was based on the considered universities rankings organizations, the US News and World Report and Times Higher Education, and on the survey distributed to industrial engineering students in Jordan, who are seeking admission for a doctorate in this field. Table 1 information also was used in building the PSI decision matrix involving the 37 universities that all have a doctorate program in industrial engineering.

Table 2. The PSI decision matrix (Xij) example.

Alternatives (A_i)	Criteria (C_j)				
	C_1	C_2	C_3	…	C_m
A_1	X_{11}	X_{12}	X_{13}	…	X_{1m}
A_2	X_{21}	X_{22}	X_{23}	…	X_{2m}
A_3	X_{31}	X_{32}	X_{33}	…	X_{3m}
…	…	…	…	…	…
A_n	X_{n1}	X_{n2}	X_{n3}	…	X_{nm}

After constructing the decision matrix, data normalizing is performed. Data of the decision matrix are transformed into values in the 0-1 range. In the case of a positive expectancy (i.e. profit), the normalization formula is:

$$R_{ij} = \frac{X_{ij}}{X_j^{max}} \tag{1}$$

While in the case of negative expectancy (i.e. cost), the normalizing formula is:

$$R_{ij} = \frac{x_j^{min}}{x_{ij}} \tag{2}$$

Where X_{ij} is the attribute measures (i = 1, 2, 3, ..., n and j = 1, 2, 3, . . . , m) in the decision matrix.

Next, the preference variation value (PV_j) is calculated based on:

$$PV_j = \sum_{i=1}^{n} [R_{ij} - \bar{R}_j]^2 \tag{3}$$

Where $\bar{R}_j$ is the mean of the normalized values of attribute j and calculated as:

$$\bar{R}_j = \frac{1}{N} \sum_{i=1}^{n} R_{ij} \tag{4}$$

Afterward, for each attribute, the deviation (Φ_j) in preference variation value (PV_j) is computed as:

$$\Phi_j = 1 - PV_j \tag{5}$$

Then, the overall preference value (Ψ_j) is computed for each attribute as:

$$\Psi_j = \frac{\Phi_j}{\sum_{j=1}^{m} \Phi_j} \quad (7)$$

Here, the overall summation of the preference value of all attributes must add to one.

Next, the preference selection index (I_i) is then calculated based on:

$$I_i = \sum_{j=1}^{m} (R_{ij} \times \Psi_j) \quad (8)$$

Finally, alternatives are ranked according to the I_i values; the one of the highest I_i value is of high preference.

3.2. The AHP model

To construct the AHP model, the following steps are required:

1. Building the decision model, which includes constructing the model as a hierarchy of objectives, attributes, and alternatives.

2. Priority (relative weight) derivation for each attribute. This is done by performing a pairwise comparison to determine the relative priority of the criteria concerning the decisive goal. At this step, it is necessary to test the judgments' consistency, which is a kind of judgment revision to guarantee an acceptable consistency level in terms of transitivity and proportionality.

3. Local preferences derivation for each alternative. In this step, priorities are derived either by a pairwise comparison for the considered alternatives concerning each criterion or by absolute comparison, in which alternatives are ranked one at a time based on single criteria intensity rating.

4. Overall priorities derivation; all the computed alternative priorities are merged as a weighted summation, to consider the weight of each attribute, for gaining the overall alternatives' priorities. Hence, a provisional decision is made such that the alternative of the highest priority is selected as the best choice.

4. Results and discussion

4.1. The PSI model

For the current study and the designed PSI decision matrix, Table 3 shows the computed values of the preference variation value (PV_j), the deviation (Φ_j) of the preference variation, and the overall preference value (Ψ_j) for each attribute being considered. These values were calculated using Equations 3, 5, and 6, respectively.

The preference selection index (I_i) values are computed according to Equation 7 for the 37 universities, considering the 20 attributes involved in the PSI model, and are shown in Table 4. The alternatives now could be ranked based on their I_i value, such that the alternative of the highest I_i value is most preferable. This finding proves that the PSI approach is suitable and faster to deal with decision problems of a large number of attributes and alternatives.

4.1.1. The PSI Model sensitivity analysis

After constructing the PSI model, a sensitivity analysis procedure was performed based on a trial and error approach. The objective of the sensitivity analysis was to eliminate attributes with smaller preference values (PV_j) and to evaluate their effect on the resulted rank.

The detailed procedure sensitivity analysis was: If eliminating a selected attribute of the lowest (PV_j) value has a minor effect on changing the obtained alternative rank, then the PSI model is then updated by eliminating that attribute (no major contribution of this attribute on the alternatives' preferences). Then, another iteration was performed to test the next attribute (of the second lowest value) and so on. The performed iterations of the PSI sensitivity analysis are described in Table 5. Table 6 shows the rank of the universities based on the performed sensitivity analysis iterations.

Table 3. The computed PV_j, Φ_j, and Ψ_j values for each attribute.

Attribute	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
PV_j	1.232	0.488	1.360	0.243	1.910	1.377	2.968	0.215	1.500	0.590
Φ_j	-0.232	0.512	-0.360	0.757	-0.910	-0.377	-1.968	0.785	-0.500	0.410
Ψ_j	0.478	-1.056	0.742	-1.561	1.876	0.777	4.058	-1.619	1.031	-0.845
Attribute	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}
PV_j	0.955	4.330	1.670	0.051	0.190	0.438	0.132	0.245	0.570	0.021
Φ_j	0.045	-3.330	-0.670	0.949	0.810	0.562	0.868	0.755	0.430	0.979
Ψ_j	-0.093	6.866	1.381	-1.957	-1.670	-1.159	-1.790	-1.557	-0.887	-2.019

Table 4. Alternatives rank based on the preference selection index value (I_i).

Alternative	I_i	Rank	Alternative	I_i	Rank
A_{13}	2.2651	1	A_{23}	-2.2519	20
A_{11}	1.8113	2	A_{18}	-2.7946	21
A_4	1.7424	3	A_{17}	-3.0343	22
A_7	1.5087	4	A_3	-3.6660	23
A_{26}	1.4543	5	A_{28}	-4.4768	24
A_{29}	0.9391	6	A_{12}	-5.5693	25
A_1	0.8659	7	A_{22}	-5.8509	26
A_2	0.4465	8	A_{19}	-6.2022	27
A_{10}	-0.0157	9	A_{25}	-6.3150	28
A_8	-0.1381	10	A_{37}	-6.3280	29
A_9	-0.3174	11	A_{33}	-6.6190	30
A_{14}	-0.6167	12	A_{35}	-6.7123	31
A_6	-0.7465	13	A_5	-7.1595	32
A_{27}	-0.7624	14	A_{24}	-7.2247	33
A_{20}	-1.5040	15	A_{15}	-7.3551	34
A_{34}	-1.5660	16	A_{16}	-7.5176	35
A_{21}	-1.7691	17	A_{36}	-8.2313	36
A_{30}	-2.0184	18	A_{32}	-8.6434	37
A_{31}	-2.2211	19			

Table 5. Description of the performed iterations.

Iteration number	Description	The effect on the initial PSI rank
I Eliminating	Eliminating the employment rate attribute (C_{20})	Minor effect; the model was updated by eliminating (C_{20})
II	Eliminating the diversity attribute (C_8)	Minor effect; the model was updated by eliminating (C_8)
III	Eliminating the sport teams attribute (C_{19})	Minor effect; the model was updated by eliminating (C_{19})
IV	the undergraduate GPA attribute (C_{14})	Minor effect; the model was updated by eliminating (C_{14})
V	Eliminating the average GRE- analytical writing score attribute (C_{18})	Minor effect; the model was updated by eliminating (C_{18})
VI	Eliminating the minimum TOEFL score attribute (C_{15})	Minor effect; the model was updated by eliminating (C_{15})
VII	Eliminating the average GRE- quantitative score attribute (C_{17})	Minor effect; the model was updated by eliminating (C_{17})
VIII	Eliminating the opportunity for part-time job attribute (C_4)	Minor effect; the model was updated by eliminating (C_4)
IX	Eliminating the average GRE- verbal score attribute (C_{16})	Minor effect; the model was updated by eliminating (C_{16})

Table 6. Summary for the resulted rank for iterations from I to IX.

A_i	Rank									
	Initial model	I	II	III	IV	V	VI	VII	VIII	IX
A_1	7	7	7	7	7	6	6	6	6	6
A_2	8	8	8	8	8	8	8	8	8	8
A_3	23	23	23	23	23	23	23	23	23	23
A_4	3	3	3	3	3	3	4	4	3	3
A_5	32	32	32	32	32	32	32	33	33	34
A_6	13	13	14	14	14	14	14	13	14	14
A_7	4	4	5	5	5	3	2	2	2	2
A_8	10	10	10	10	10	10	11	11	11	12
A_9	11	11	11	11	11	11	10	10	10	9
A_{10}	9	9	9	9	9	9	8	8	9	9
A_{11}	2	2	2	2	2	2	2	2	4	3
A_{12}	25	25	25	25	25	25	25	25	25	25
A_{13}	1	1	1	1	1	1	1	1	1	1
A_{14}	12	12	13	13	13	13	12	12	13	12
A_{15}	34	33	33	33	33	33	33	32	31	30
A_{16}	35	35	34	34	34	34	34	33	33	32
A_{17}	22	22	22	22	22	22	21	21	21	21
A_{18}	21	21	21	21	21	21	21	22	22	22
A_{19}	27	27	27	27	27	26	26	25	26	25
A_{20}	15	15	16	16	16	15	15	15	15	15
A_{21}	17	17	17	18	17	17	16	16	16	17
A_{22}	26	26	26	26	26	27	27	27	27	28
A_{23}	20	20	20	20	20	18	18	16	16	15
A_{24}	33	34	34	35	35	35	35	35	35	35
A_{25}	28	28	29	29	29	29	28	28	28	28
A_{26}	5	5	4	4	4	5	5	5	5	5
A_{27}	14	13	12	12	12	12	13	13	11	11
A_{28}	24	24	24	24	24	24	24	24	24	24
A_{29}	6	6	6	6	6	6	7	7	7	7
A_{30}	18	18	18	17	17	20	20	20	20	20
A_{31}	19	19	19	19	19	18	18	19	19	18
A_{32}	37	37	37	37	37	37	37	37	37	37
A_{33}	30	30	30	30	31	31	31	31	32	32
A_{34}	16	16	15	15	15	15	16	16	16	18
A_{35}	31	31	31	31	30	30	30	29	28	27
A_{36}	36	36	36	36	36	36	36	36	36	36
A_{37}	29	28	27	27	28	28	28	29	28	30

4.2. The AHP model

Breaking down the decision problem into a hierarchy structure is an essential step. It helps to analyze the decision and increase the decisión maker understanding of the decision problem. The basic components of the hierarchy are shown in Figure 1.

The hierarchy upper level represents the decision goal, which was selecting an appropriate university in the U.S. for pursuing a doctorate in industrial engineering. The second level represents the criteria that will be used to decide the university selection. In the case of selecting a university, if the initial criteria were used directly to build the AHP model without starting with the PSI model, the resulted hierarchy will be as shown in Figure 2. Figure 2 shows that the hierarchy was complicated as it had several criteria, and some of these criteria have their sub-criteria. To reduce the number of criteria considered, the previous PSI model results were considered. This means instead of having all the 20 attributes and the 37 alternatives and studying them again in the AHP model, the most significant attributes and the highly preferred alternatives obtained in the PSI model will be considered in building the AHP model. Figure 3 shows the considered hierarchy for the AHP model after considering the PSI model outcomes.

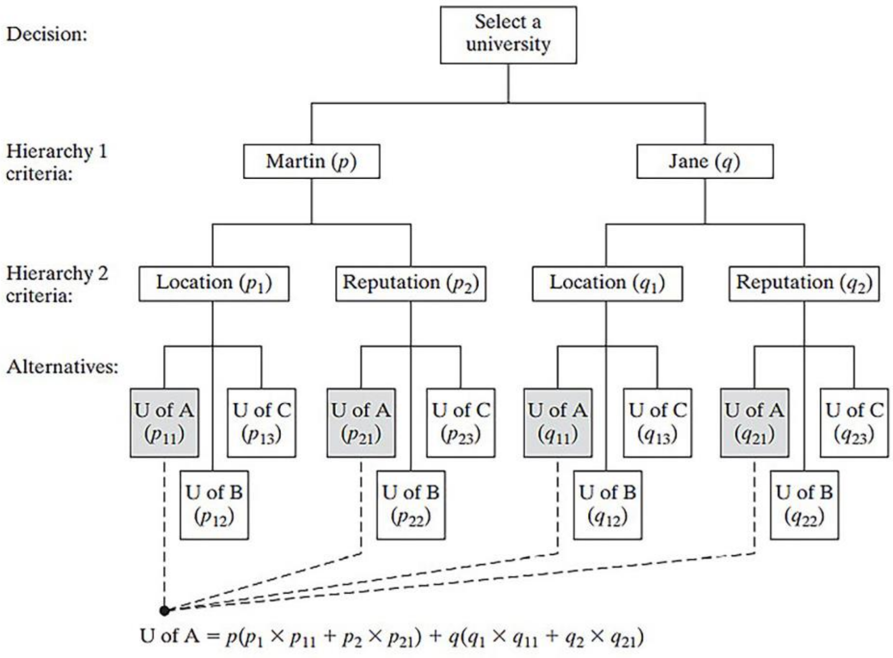

Figure 1. The basic components of an AHP hierarchy (Taha, 2011)

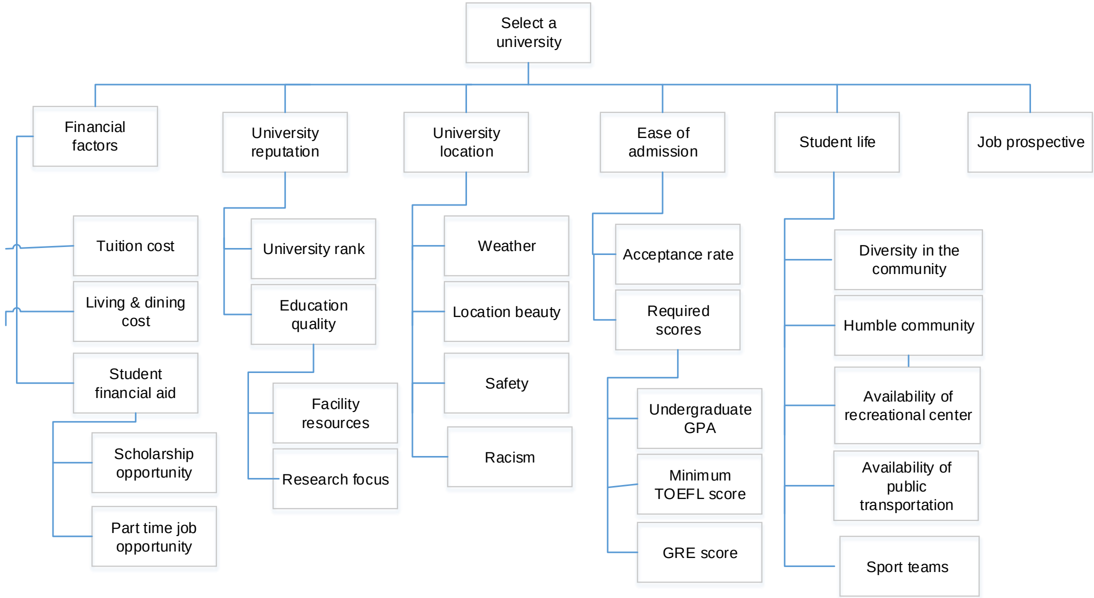

Figure 2. The suggested AHP hierarchy without considering the PSI results.

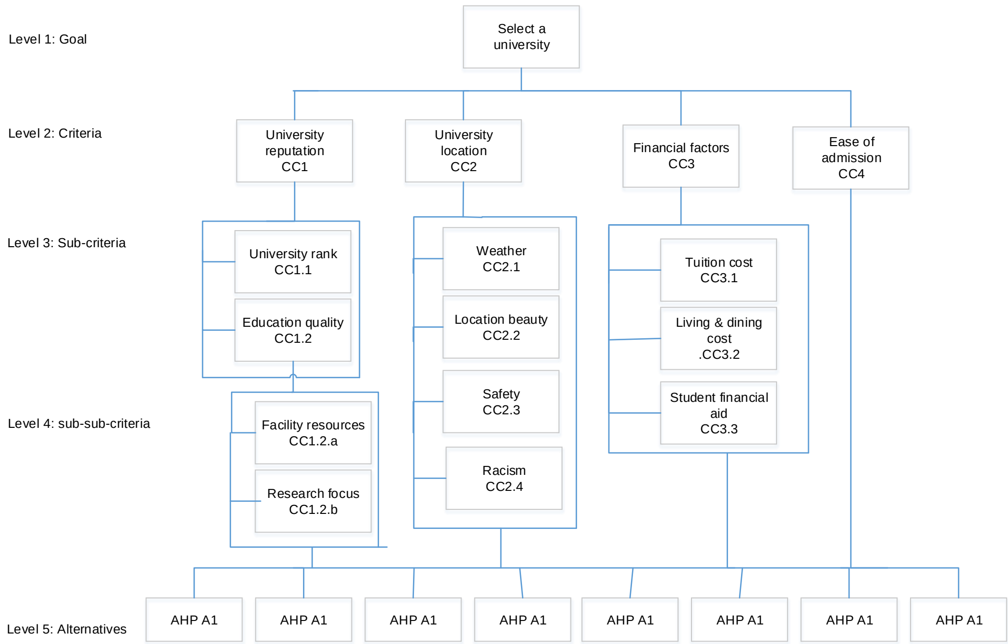

Figure 3. The AHP hierarchy considers the outcomes of the PSI model.

From the hierarchy shown in Figure 3, it is obvious that the main criteria level included only four criteria that were university reputation (CC1), university location (CC2), financial factors (CC3), and ease of admission (CC4). The university's reputation was measured by two sub-criteria, the university rank (CC1.1) and the education quality(CC1.2). The education quality was divided into the facility resources (CC1.2a) and the research focus (CC1.2b). The university location (CC2) criterion included weather (CC2.1), location beauty (CC2.2), safety (CC2.3), and racism (CC2.4). The financial factors (CC3) criterion was divided into tuition cost (CC3.1), living and dining expenses (CC3.2), and student financial aid (CC3.3). Student financial aid was evaluated by scholarship opportunities. The fourth main criterion was the ease of admission (CC4) and it was measured by the admission rate. Table 7 summarizes the criteria sub-criteria that were used in this study. In addition, Table 7 provides similar research based on the literature considering the selected criteria or sub-criteria.

The next step in building the AHP model was deriving priorities. The relative weights (priorities) for the criteria were derived. These priorities were also called relative importance because the computed priorities of criteria were measured concerning each other. The priorities were derived using pairwise comparisons, which were made easily using the Saaty numeric scale of values between 1 and 9. To derive priorities for the main criteria, pairwise comparisons should be made between the levels of the main criteria level (university reputation, university location, financial factors, and ease of admission requirements).

In this study, the PSI was initially used to compare a total of 37 universities (alternatives) according to 20 different attributes. Based on the PSI results, a set of eight alternatives were selected from the PSI model as shown in Table 8. The alternatives had different PSI values (I_i) and varied performance on the AHP model sub-criteria. Data of the alternative's performance on each sub-criteria were taken from the PSI model. In the AHP model, eight alternatives of the highest PSI values (I_i) were considered. In addition, the pairwise comparison that reflects the decisión-maker preferences of criteria and sub-criteria was made. Expert Choice © software was used to handle the AHP model. After obtaining the AHP model, a sensitivity analysis procedure was conducted to evaluate the AHP model.

Table 7. Important criteria are considered to build the AHP model of a university selection.

Main criteria	Subcriteria	Similar literature
University reputation	-University rank -Education quality (quality of teaching)	(Price et al., 2003), (Agrey & Lampadan, 2014) (Soutar & Turner, 2002), (Parameswaran & Glowacka, 1995), (Ojo et al., 2013), (Shammot, 2011), (Misran, et al., 2012),(Bin Yusof et al., 2008)
University location	- Weather - Location beauty - Racism - Safety	(Cubillo et al., 2006), (Parameswaran & Glowacka, 1995),(Ojo et al., 2013) (Misran, et al., 2012), (Bin Yusof et al., 2008)
Financial factors	- Tuition fees - Living and dining costs - Student financial aid	(Eder et al., 2010), (Mazzarol & Soutar 2002) (Bodycott, 2009), (Patton, 2000) (Agrey & Lampadan, 2014), (Parameswaran & Glowacka, 1995), (Ojo et al., 2013) (Shammot, 2011), (Bin Yusof et al., 2008), (Kabak & Dağdeviren, 2014)
Ease of admission	Measured by the university admission rate for a doctoral program	(Röding & Nordenram, 2005)

Table 8. The selected alternatives and their abbreviations in the AHP model.

University	Abbreviation in the AHP model
Georgia Institute of Technology	alt1
University of Texas - Austin	alt2
University of Pittsburgh	alt3
Kansas State University	alt4
Columbia University	alt5
Auburn University	alt6
Binghamton University	alt7
Montana State University	alt8

For each level in the AHP hierarchy, pairwise comparisons for each node with its children nodes were made. To illustrate, Table 9 represents the pairwise comparisons of the main criteria considered in the AHP model concerning the decisive goal in this study. The inconsistency of this matrix was 0.03, which is an acceptable level as it is less than 10% (Taha, 2011). The Expert Choice software compared the priority of the row concerning the column and put the values in the upper triangular of the matrix. For example, the reputation (the criterion in the row) is (7), which means that it is more important than the location (the criterion in the column). Similarly, comparisons were done for the other nodes.

As mentioned previously, the model rated each alternative concerning its performance on each criterion. From the PSI data, the performance of alternatives was evaluated regarding each criterion. Table 10 summarizes each alternative in detail, the first column shows the performance of alternatives regarding university rank (CC1.1). For example, alt1 (Georgia Institute of Technology) in the AHP model was ranked in the top 10 universities, the second column represents the perfor mance of alternatives regarding facility resources (CC1.2.a), and these numbers were taken from the facility resources attribute in the decision matrix of the PSI model, similarly for the research focus (CC1.2.b). Regarding the weather (CC2.1), the weather attribute in the PSI model was used such that the weather was categorized into excellent weather, average weather, and bad weather. For the location beauty (CC2.2), the data for the location beauty attribute in the PSI model was used. Regarding safety (CC2.3), the data for the safety attribute in the PSI model was also used. Similarly, for racism (CC2.4), the data for racism attribute in the PSI model was considered. For the financial factors sub-criteria; tuition fees (CC3.1), living and dining expenses (CC3.2), and student financial aid (CC3.3), the attributes data of the PSI model were used. Furthermore, the student's scholarship opportunity attribute in the PSI model was used as a source of data for the student aid (CC3.3). Finally, for the last column ease of admission (CC4), data from the admission rate attribute were used. The relative weights of the AHP model's main criteria are shown in Table 11.

Table 9. Entries for the pairwise comparisons of the main criteria of this study.

Criterion	Reputation	Location	Financial factors	Ease of admission
Reputation	1	7	3	2
Location		1	1/3	1/9
Financial factors			1	1/3
Ease of admission				1
Inconsistency	0.03			

Table 10. The AHP alternatives' specifications based on the PSI data.

	University rank (CC1.1)	Facility resources (CC1.2.a)	Research focus (CC1.2.b)	Weather (CC2.1)	Location beauty (CC2.2)	Safety (CC2.3)	Racism (CC2.4)	Tuition fees (CC3.1)	Living and dining expenses (CC3.2)	Student financial aid (CC3.3)	Ease of admission (CC4)
Alt1	Top10	14.1	96.1	Exc.	Top40	low	1.2	28,500	11,000	60	29.9
Alt2	Top30	16.3	87.9	Exc.	Top30	low	1.2	18,500	10,000	50	16.1
Alt3	Top20	18.1	25.7	Avg.	Top40	high	1.2	42,500	11,000	100	26.2
Alt4	Top60	11.9	14.1	Avg.	Top50	low	1.2	16,500	9,000	100	23.7
Alt5	Top20	27.1	62.8	Bad	Top30	high	3.6	45,000	13,000	40	10.6
Alt6	Top40	11	22.7	Exc.	Top40	low	3.6	28,000	13,000	90	45.9
Alt7	Top70	11.1	19.2	bad	Top30	high	3.6	22,000	13,500	60	70.2
Alt8	No rank	21.6	11.1	bad	Top10	Avg.	6	11,500	9000	70	67.7

Table 11. The main criteria relative weights.

Criteria	Relative weight
University reputation	0.467
University location	0.049
Financial factors	0.135
Ease of admission	0.349
Total	1

The relative weights shown in Table 11 indicate that the university reputation is the most important criterion with a relative weight of 46.7%, followed by the ease of admission criterion with a relative weight of 34.9%, then by financial factors criterion with a relative weight of 13.5%, and the university location of a relative weight 4.9%. A higher weight means higher preferences of the decisión-maker.

Now, considering the university reputation sub criteria in the AHP model, the university rank occupied the highest priority of 83.3%, while the education quality occupied only 16.7%. For the education quality sub-subcriteria, the facility resources had a priority of 83.3%, followed by the research focus of 16.7% in weight. Regarding the financial factors sub criteria, a tie was found between the relative weights of the living and dining expenses and student financial of 45.45%, while that for the tuition of 9.1%. Regarding the university location sub-criteria, safety had the highest priority of 65.85%, followed by location beauty with a relative weight of 15.4%, weather with a relative weight of 13.15%, and finally the racism with a relative weight of 5.6%. The weight of each alternative regarding each main criterion was combined to obtain the overall weight as shown in Table 12.

Based on Table 12 and for the university reputation criterion, alt5 (Columbia University) had the highest priority of 18.9% followed by alt1 (Georgia Institute of Technology) with a priority of 18.5%, while alt8 (Montana State University) had the least priority of 2.1%. Considering the university location criterion, alt3 (University of Pittsburgh) occupied the highest priority of 14.9%, followed by a tie between alt5 (Columbia University) and alt7 (Binghamton University) with 14.5% in weight, while alt4 (Kansas State University) was of the least weight of 10.4%. Regarding the financial factors criterion, alt4 (Kansas State University) had the highest weight of 17.6% while alt5 (Columbia University) was of the least weight of 7.1%. Regarding the ease of admission criterion, three alternatives were tied regarding admission rate of 52.2%, these were alt6 (Auburn University), alt7 (Binghamton University), and alt8 (Montana State University) had the highest weight of 25.2%, while alt5 (Columbia University) had the least weight of 0.4%.

As mentioned previously, the AHP model combined all weights of the alternatives and provided an easy conclusion for the user. Table 13 shows the total weights and the rank of the eight alternatives in the AHP model.

According to Table 13, Auburn University (alt6) was the most preferred alternative as it had a maximum weight of 16%. Georgia Institute of Technology (alt1) was found to be the next students' preference with a total weight of 14%, followed by the University of Pittsburgh (alt3) with a weight of 13.5%. Kansas State University (alt4) had the least weight at 9.5%.

4.2.1 The AHP sensitivity analysis

The total weights obtained previously in the AHP model could be changed if the priority of the criterion is changed. For this reason, the sensitivity of the decision to changes in the relative weights must be considered. The Expert Choice software was used to obtain a performance sensitivity graph for the model, as shown in Figure 4. This graph is a dynamic graph that is consisting of two axes. The horizontal axis that represents the as shown in Figure 4. This graph is a dynamic graph that is consisting of two axes. The horizontal axis that represents the criteria axes, which measu the total weight of each alternative as the priority given to criteria change; and the vertical axis is the objective axis, which represents the relative importance of each main criterion considered in the model. Figure 4 shows the AHP model results in that Alt6 (Auburn University) is the most preferred university.

To perform the sensitivity analysis, the priority of criteria was changed randomly and then the priority of alternatives was monitored. In Figure 5, more weight was given to the university's reputation, the new priorities were 70%, 10%, 10%, and 10% for university reputation, university location, financial factors, and ease of admission, respectively. Under this scenario, alt1 (Georgia Institute of Technology) was the most recommended alternative. Note that alt6 (Auburn University) had a total relative weight of 16% in the previous model while alt1 (Georgia Institute of Technology) had a relative weight of 14%, which are close to each other.

Now, considering a new scenario, of giving a higher priority for the ease of admission criterion. Figure 6 shows the result after modifying the new priorities into 10%, 10%, 10%, and 70% for university reputation, location, financial factors, and ease of admission, respectively. This change kept alt6 (Auburn University) as the preferred alternative.

Another scenario was performed by giving the university location a higher priority, thus, the new priorities were 10%, 70%, 10%, and 10% for university reputation, university location, financial factors, and ease of admission, respectively. As shown in Figure 7, these priorities changed the decision by making alt3 (University of Pittsburgh) the most preferred. This implies that the model is sensitive to the change of criteria weights.

Similarly assigning more weight to the financial factors, change the decision. Figure 8 shows that when the new priorities become 10%, 10%, 70%, and 10% for university reputation, university location, financial factors, and ease of admission, respectively, alt4 (Kansas State University) becomes the preferred alternative.

Table 12. The weights of alternatives concerning the main criteria.

Alternative	University name	Relative weight			
		University reputation	University location	Financial factors	Ease of admission
Alt1	Georgia Institute of Technology	0.185	0.112	0.119	0.085
Alt2	University of Texas-Austin	0.154	0.114	0.125	0.027
Alt3	University of Pittsburgh	0.170	0.149	0.144	0.069
Alt4	Kansas State University	0.089	0.104	0.176	0.059
Alt5	Columbia University	0.189	0.145	0.071	0.004
Alt6	Auburn University	0.122	0.110	0.121	0.252
Alt7	Binghamton University	0.070	0.145	0.093	0.252
Alt8	Montana State University	0.021	0.121	0.152	0.252

Table 13. Total weights of the considered universities concerning the AHP model.

University name	Abbreviation in the AHP model	Total weight	Rank
Georgia Institute of Technology	Alt1	0.140	2
University of Texas - Austin	Alt2	0.109	7
University of Pittsburgh	Alt3	0.135	3
Kansas State University	Alt4	0.095	8
Columbia University	Alt5	0.112	6
Auburn University	Alt6	0.160	1
Binghamton University	Alt7	0.132	4
Montana State University	Alt8	0.117	5

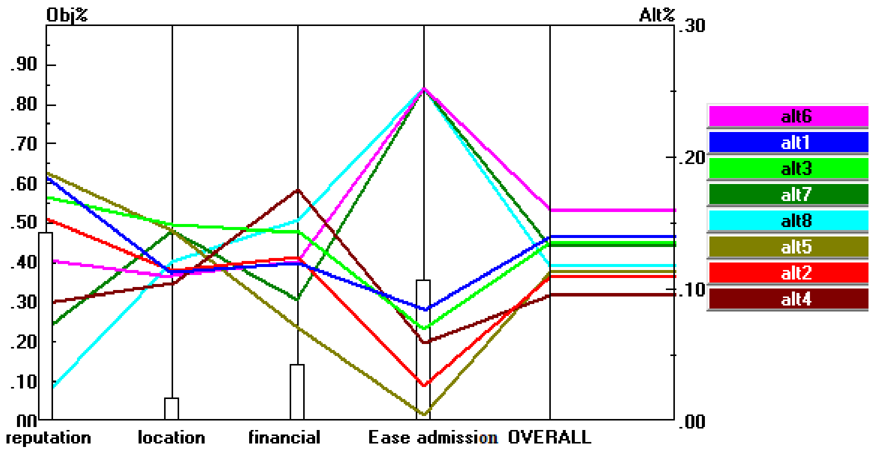

Figure 4. Performance sersnitivity graph for the AHP model with alt6 (Auburn University) is the most favorable.

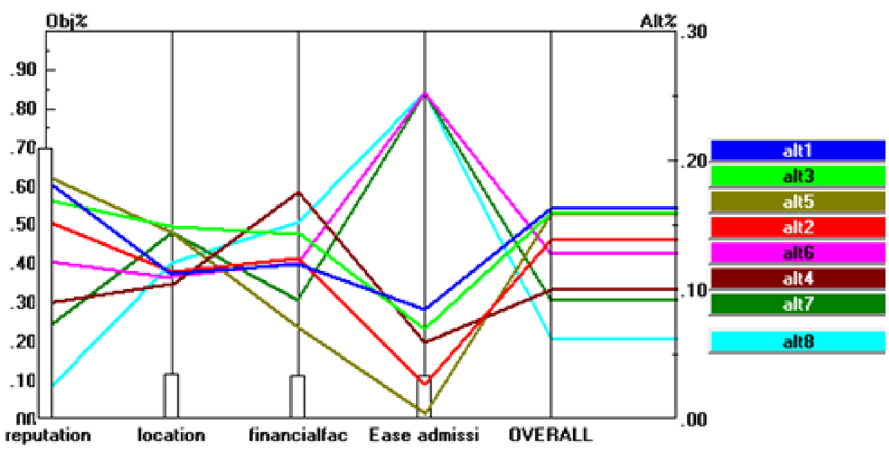

Figure 5. Performance sensitivity graph for the AHP model with relative weights of 70%, 10%, 10%, and 10% for reputation, location, financial factors, and ease of admission, respectively.

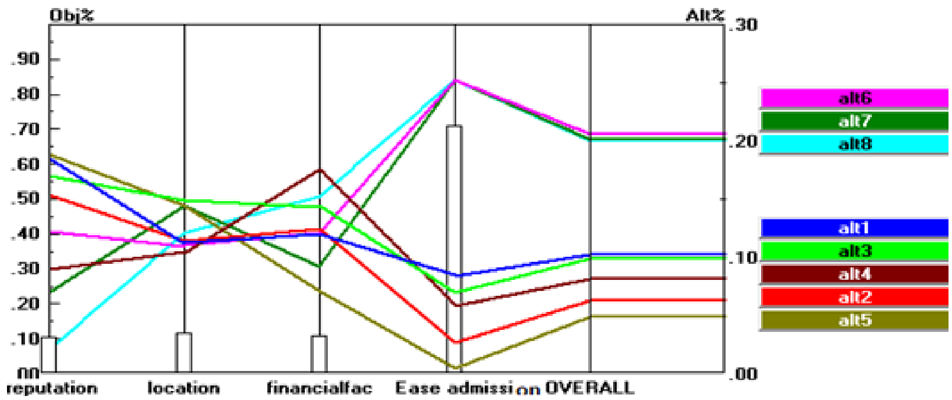

Figure 6. Performance sensitivity graph for the AHP model with relative weights of 10%, 10%, 10%, and 70% for reputation, location, financial factors, and ease of admission, respectively.

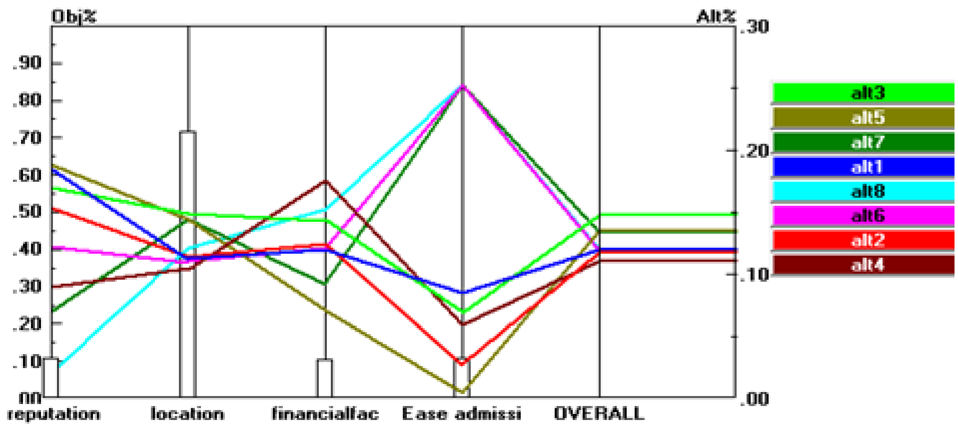

Figure 7. Performance sensitivity graph for the AHP model with relative weights of 10%, 70%, 10%, and 10% for reputation, location, financial factors, and ease of admission, respectively.

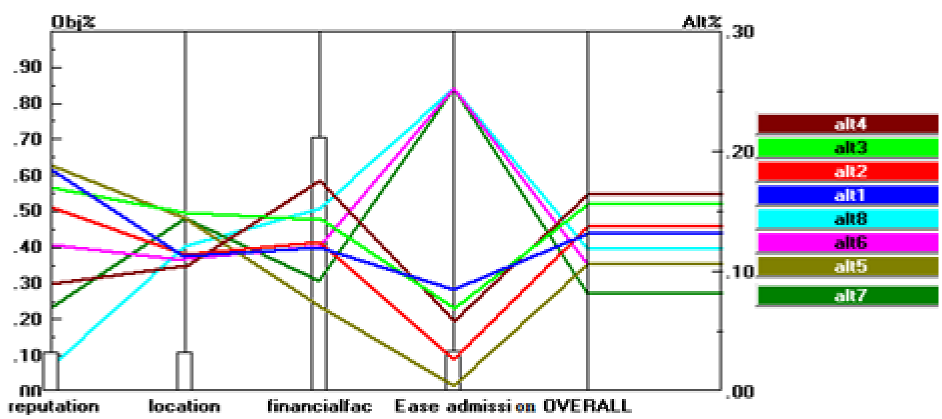

Figure 8. Performance sensitivity graph for the AHP model with relative weights of 10%, 10%, 70%, and 10% for reputation, location, financial factors, and ease of admission, respectively.

5. Conclusions

This paper provides a decision-making problem using the PSI and AHP techniques. A case study of selecting a U.S. university for an international student to pursue a doctorate degree in industrial engineering was considered. Initially, the PSI model was constructed considering 37 alternatives and 20 attributes. The PSI model benefits in ranking the 37 universities based on the attributes considered. A sensitivity analysis was conducted for the PSI model to find the most effective attributes of the decision. Afterward, the PSI model outcomes benefit the construction of the AHP model by minimizing the number of alternatives and attributes being considered. Eight alternatives and four main criteria were considered in the AHP model instead of the initial 37 alternatives and 20 attributes.

The obtained AHP model priorities reflected the preferences of a student seeking to pursue a doctorate degree in industrial engineering in the U.S. The overall weights of the 8 alternatives were calculated, and Auburn University was found to be the best alternative. The results of the AHP model showed that university reputation occupied the highest priority, followed by the ease of admission, financial factors, and university location. In addition, for this decision, sensitivity analysis was performed, as priorities might be changed based on students' preferences.

This study provides a systematic approach that helps students who are searching for a suitable university in the U.S. to select the best university that satisfies their needs. Although this study adopted alternatives related to the industrial engineering student, the model had rated the alternatives rather than relative comparison, which made the model more flexible. Therefore, this model could assist students of different disciplines who are searching for a doctorate degree admission in the U.S. The large number of alternatives and attributes found in this case study proved that the PSI technique could handle large MCDM decision-making problems, which was not seen that much in the previous literature.

For future studies, researchers may expand the scope of the problem being considered in the study by including all alternatives (universities) in the U.S. that offer doctorate and including the U.S. Visa limitation as a criterion.

Conflict of interest

The authors have no conflict of interest to declare

Funding

The authors received no specific funding for this work.

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