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Method Article

Generic algorithm for multicriteria ranking of crop technological options based on the "Technique for Order of Preference by Similarity to Ideal Solution" using ShinyApps

Aymen Frija[a,*], Hassen Ouerghemmi[a], Firas Ismail[b], Sika Gbegbelegbe[c], Nedumaran Swamikannu[d]

[a] *International Center for Agricultural Research in the Dry Areas (ICARDA)*
[b] *Institut National des sciences Appliquées et de Technologie (INSAT)*
[c] *International Institute of Tropical Agriculture (IITA)*
[d] *International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)*

A B S T R A C T

Many agricultural research and development programs aiming at enhancing tradeoffs related to different adoption, management and policy decisions face a methodological problem in which multi-criteria ranking is used to reach acceptable compromises between different objectives (e.g. those of farms, research managers, donors or policy makers). A typical situation is where many farm management options will result in different conflicting economic, social and environmental impacts. Ranking these options and the choice of those to promote is challenging. The literature provides a set of methodological solutions that need background data organization and simulation through coding using different computing software. Here, we provide a generic solution and friendly interface, made on Shiny (an R-package) based on the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). We apply this method for ranking different crop technological products of grain legumes and dry cereals based on their respective impacts on poverty, child malnutrition and economic benefits in more than 40 countries in eight different geographic zones across South Asia and Sub-Saharan Africa.

• The developed algorithms and interface can help rank different options based on the weights (preferences) of their respective outcome indicators.
• The interface allows for changing the weights (preferences) and automatically generates new ranking tables and graphs accordingly, which can serve for scenario simulations, which saves time compared to manually performing these calculations.

* Corresponding author.
E-mail address: a.frija@cgiar.org (A. Frija).

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Subject Area:	*Agricultural and Biological Sciences*
More specific subject area:	*This method is highly suitable for all problems where tradeoff assessments and compromises across conflictual objectives need to be defined. Such problems are usually at the interface between agricultural sciences, environmental sciences and development. Such decision problems also partly involve social sciences because decisions to rank options are based on the preferences of the decision maker for given attributes (environmental vs income, or short vs long term). The method allows changing these preferences by altering the weights (i.e. the importance) attributed to each evaluation criterion.*
Method name:	*TOPSIS_ShinyApp*
Name and reference of original method:	*"Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)" by: C.-L. Hwang, K. Yoon. Multiple Attribute Decision Making (Vol. 186). Springer, Berlin Heidelberg, 1981.* https://doi.org/10.1007/978-3-642-48318-9.
Resource availability:	https://shiny.rstudio.com/ https://rstudio.com/products/rstudio/download/ https://github.com/fyras1/GLDC-ICARDA

Presentation of the TOPSIS ranking method

The technique for ordering preference by similarity to an ideal solution was first presented by Hwang & Yoon [4] as an alternative for solving multi-attribute decision problems [3] where a decision must be made based on different attributes (or indicators). The method is part of the techniques known as multi-criteria for decision making (MCDM) [9]. It is particularly used for ranking or selecting one or more options (or alternatives) from among a finite number [3] with respect to multiple criteria [12]. Each of the options in the choice set is defined over the number of specific criteria. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is relatively simple to apply, and is suitable for situations where there are a large number of criteria and alternatives [10].

The method originates from the concept of a displaced ideal point from which the compromise solution has the shortest distance [2]. This involves seven steps as follow (see also Table 1):

1. Create an evaluation matrix consisting of m alternatives and n criteria.
2. Normalize the created matrix.
3. Calculate the weighted normalized decision matrix: weights for each evaluation criteria can be specified in an ex-ante manner, thus reflecting the preferences of the evaluator (stakeholder) for one criterion or another. Equal weights can be used as default. The sum of all weights should equal 1.
4. Determine the ideal and anti-ideal solutions according to this logic.
5. Calculate the Euclidian distance between the target alternative and the worst condition, and the distance between the target alternative and the best condition.
6. For each alternative, calculate the relative closeness to the ideal solution allowing the ranking of available options from the best to the worst.
7. Rank all alternatives based on their respective scores.

According to Kim et al. [5] and Shih et al. [10], TOPSIS has some advantages compared to other MCDM methods. These include (i) help considering human rationale in the ranking of options, (ii) generating a scalar value referring to both the best and worst alternatives simultaneously and (iii) straightforward computation steps that are easily converted into scripts and spreadsheets.

Table 1
Different mathematical steps and their R scripts.

TOPSIS step	Generic mathematical format	R scripts developed for the example we considered

1	Assume n options and 3 criteria: BCR, Poverty, and Nutrition	`ls<-list();`
		`df9<-data.frame();`
		`for (i in 1:8){`
		`fileName<-paste0("data/data_",as.character(i),".csv");`
		`df<-data.frame();`
		`df<-read.csv(fileName);`
		`names(df)<-c("ID","Crops","Technology_Options","BCR","Poverty","Nutrition")`
		`ls<-c(ls,list(df))`
		`df9<-rbind(df9,df)`
		`}`
		`ls[9]<-df9;`
		`ls[10]<-df9;`

2	$R = (r_{ij})_{m\times n}$, using the normalization method
	$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^{m} x_{kj}^2}},\ i = 1,2,\ldots,m,\ j = 1,2,\ldots..,n$
		`stnd<-function(x)`
		`{`
		`x<-x/sqrt(sum(x^2))`
		`x`
		`}`

3	$t_{ij} = r_{ij}.w_j,\ i = 1,2,\ldots,m,\ j = 1,2,\ldots,n$
	Where $w_j = {W_j}/{\sum_{k=1}^{n} W_k},\ j = 1,2,\ldots,n\ so\ that\ \sum_{i=1}^{n} w_i = 1$
		`trans<-function(df,c1,c2,c3){`
		`dfx<-df`
		`dfx$score=0;`
		`dfx$BCR<-stnd(dfx$BCR)*c1`
		`dfx$Poverty<-stnd(dfx$Poverty)*c2`
		`dfx$Nutrition<-stnd(dfx$Nutrition)*c3`
		`dfx`
		`}`

4	$A_w = \{\langle \max(t_{ij} \mid i = 1,2\ldots,m) \mid j \in J_-\rangle,\ \langle \min(t_{ij} \mid i = 1,2\ldots,m) \mid j \in J_+\rangle\} \equiv \{t_{wj} j = 1,2,\ldots,n\}$, $A_b = \{\langle \min(t_{ij} \mid i = 1,2\ldots,m) \mid j \in J_-\rangle,\ \langle \max(t_{ij} \mid i = 1,2\ldots,m) \mid j \in J_+\rangle\} \equiv \{t_{bj} j = 1,2,\ldots,n\}$	`vp<-c(max(df2[,4]), max(df2[,5]), max(df2[,6]))` `vm<-c(min(df2[,4]), min(df2[,5]), min(df2[,6]))`

5	$d_{iw} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{wj})^2},\ i = 1,2,\ldots m,$
	$d_{ib} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{bj})^2},\ i = 1,2,\ldots m,$
		`sim<-0`
		`sip<-0`
		`for(i in 1:nrow(df2)){`
		`for(j in 4:6){`
		`sip<-sip+(df2[i,j]-vp[j-3])^2`
		`sim<-sim+(df2[i,j]-vm[j-3])^2`
		`}`
		`sim<-sqrt(sim)`
		`<-sqrt(sip)`
		`df2[i,"sip"]<-sip`
		`df2[i,"sim"]<-sim`
		`sim<-0`
		`sip<-0`
		`}`

6	$S_{iw} = \frac{d_{iw}}{d_{iw}+d_{ib}},\ 0 \le S_{iw} \le 1,\ i = 1,2,..,m.$	`df2$p<-df2$sim/(df2$sim+df2$sip)`

7	NA	`dfx<-df`
		`dfx$p<-df2$p`
		`dfx<-dfx[order(-dfx$p),]`

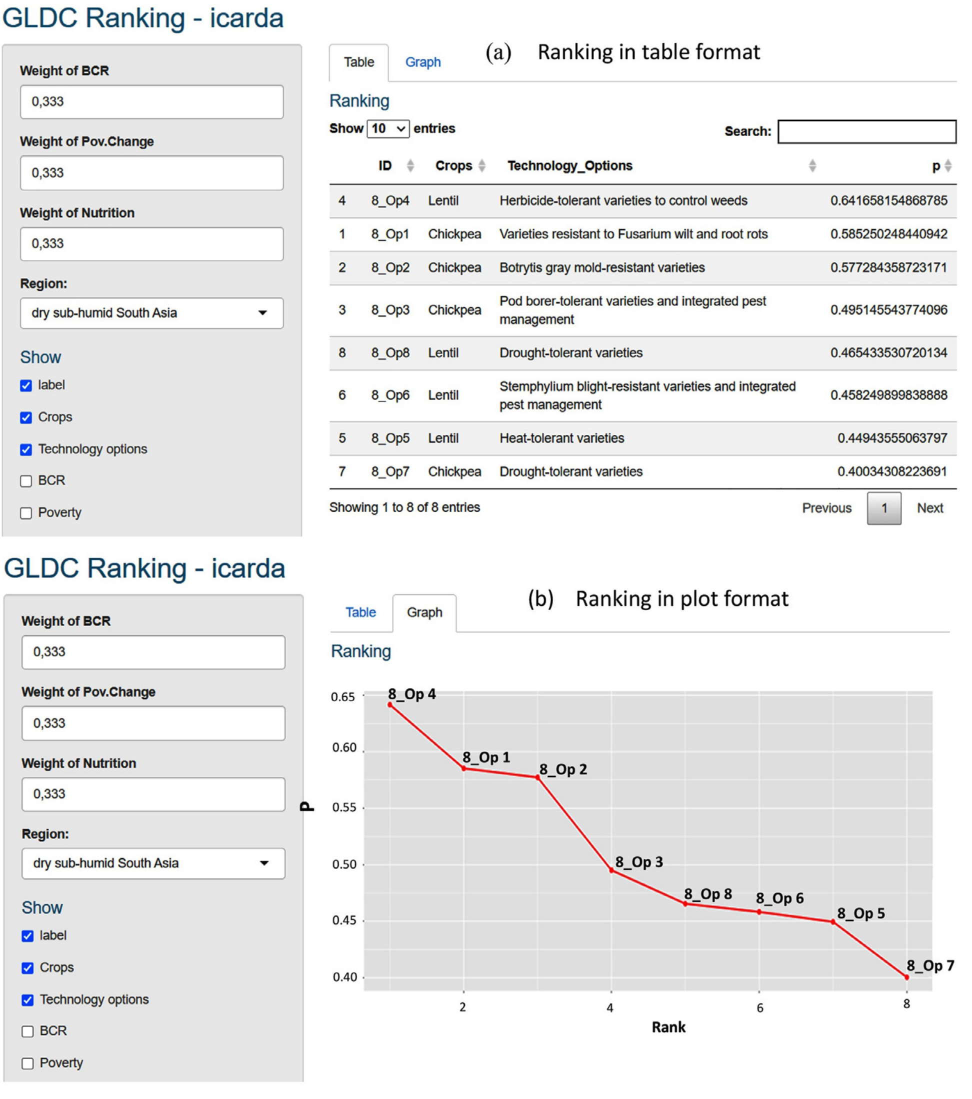

Fig. 1. Screen capture of the TOPSIS_ShinyApp for GLDC technologies ranking given in (a) table format and (b) plot format.

Rationale for developing TOPSIS_ShinyApp

Yadav et al. [11] developed Python scripts for TOPSIS, thus making the method easier and affordable for those familiar with the Python language. Mahmoud [6] has also developed R scripts to help solving multi-criteria problems using this software. However, for these unfamiliar with such coding platforms, and especially when requiring repetitive runs of TOPSIS for different weighting factors and scenarios, the tasks would remain onerous.

For these reasons we developed a user-friendly interface using the R language, and a Shiny package[1] that can quickly and easily generate ranking results for every change of criteria weights.

[1] *See the following open access permanent GitHub link to the source codes behind the implementation of this Shiny app (all files and codes can be found in this link):* https://github.com/fyras1/GLDC-ICARDA

Table 2
Different weighting scenarios used in TOPSIS_ShinyApp for ranking GLDC options.

Scenarios	Children malnutrition weight	Poverty weight	BCR ratio weight
Scenario 0	0.333	0.333	0.333
Scenario 1	0.262	0.253	0.485
Scenario 2	Different weights calculated for each zone based on real macro data (Table 3)		

The application was developed to empirically analyze a foresight problem aiming at prioritizing research for development investments based on their expected impact. The conceptual model and methodological steps are given in Table 1.

Conceptual improvements to the TOPSIS method

TOPSIS_ShinyApp was developed over three steps:

1) Data preparation and calculation of the p-values (similarity index) for each alternative using R (Table 1, steps 1–7).
2) The scripts coded in R and Shiny are then deployed in ShinyApps.io (developed by RStudio), to develop an online dashboard (interface) that can be used repeatedly for different weighting (preference scenarios) and tradeoff assessments (see Fig. 1 for a screen capture).
3) For each change made on dropdown menus of the dashboard, a new table and a figure, ranking the list of considered alternatives, are automatically generated and can thus be copied for final reporting of data analysis. Table illustration on the dashboard is part of the Shiny modeling, while the figures are generated using the ggplot2 package of R (Fig. 1 and 2).

Method validation

The TOPSIS_ShinyApp was used to rank different agricultural crop technologies tailored to enhance the yield of different grain legumes and dry cereal (GLDC) crops based on their respective impact on cost/benefit ratio, poverty and malnutrition at country levels. Forty countries, where GLDC crops are important, in Asia and Africa were considered. The full list of countries and GLDC technological options assessed are given in Supplementary material 1. This additional material provides the full list of what we call “Alternatives” (or options) in TOPSIS. These are basically combinations of “GLDC crops × Appropriate respective technologies” relevant for different countries and regions (see Supplementary material 1 for more details). The impact of each of these options on three indicators/criteria (cost/benefit ratio, poverty and undernutrition) at national level (see Supplementary material 2), has been assessed and reported using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model [7,8]. More details on adoption scenarios of these options and their respective impact assessments can be found in Arega et al. [1]. The list of options was ranked in order to provide clear guidance to the GLDC CGIAR Research Program[2] (CRP) on priority investments and crops, technologies and target countries to be considered by this research-for-development project portfolio. Thus, came the utility of TOPSIS_ShinyApp to assist with this prioritization exercise. An overview of the outputs of this empirical application of TOPSIS_ShinyApp is found below (for three different weighting scenarios shown in Table 2).

These scenarios (Tables 2 and 3) can be tested rapidly as shown in Fig. 2a–c, where we ranked the “Technology × Crop” alternatives (called options in these figures) in dry sub-humid south Asia under each of the scenarios 0, 1 and 2. Fig. 2 shows that the ranking order of the different tested options changes as the weights of the Benefit/Cost ratio, Malnutrition, and Poverty indicators are changed.

[2] https://www.cgiar.org/research/program-platform/grain-legumes-and-dryland-cereals/

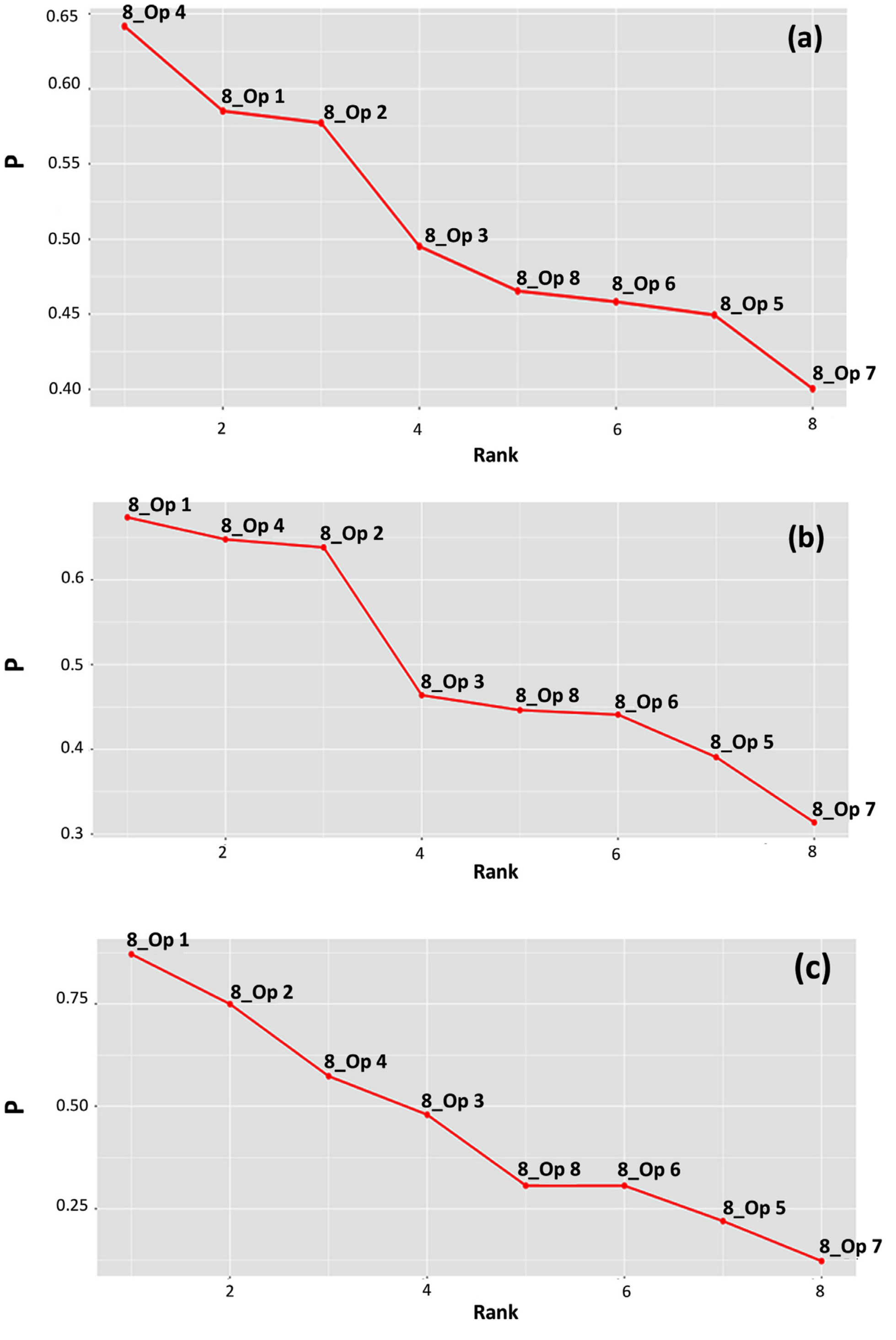

Fig. 2. Technology options classification in dry sub-humid South Asia under weighting scenarios (a) 0, (b) 1 and (c) 2.

Table 3
Different weights in scenario 2 for each of the eight zones.

Zone	Child Malnutrition Weight	Poverty Weight	BCR Weight
Dry sub-humid Eastern Africa	0.232	0.312	0.456
Dry sub-humid Southern Africa	0.201	0.362	0.437
Dry sub-humid Southern Asia	0.378	0.93	0.529
Dry sub-humid Western Africa	0.235	0.264	0.501
Semi-arid Eastern Africa	0.259	0.272	0.469
Semi-arid Southern Africa	0.22	0.316	0.464
Semi-arid Southern Asia	0.378	0.93	0.529
Semi-arid Western Africa	0.265	0.234	0.501

Conclusions

This paper highlights a generic way to run TOPSIS under different weighting scenarios using a user-friendly interface, called TOPSIS_ShinyApp. The method allows the avoidance of many of the TOPSIS steps and provides results in an automated way. The method relies on algorithms coded using the R language and can be used by many researchers focusing on trade-off analysis and multi-criteria decision making. An application of the method to a practical ranking problem for policy making was used to illustrate and validate the method.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.mex.2021.101519.

References

[1] A. Arega, S. Nedumaran, S. Gbegbelegbe, K. Mausch, P. Carberry, Ex-ante Evaluation of Research and Technology Options for Grain Legumes and Dryland Cereals in Sub-Saharan Africa and South Asia, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), 2019 https://repo.mel.cgiar.org/handle/20.500.11766/10233.
[2] S.M. Belenson, K.C. Kapur, Algorithm for solving multicriterion linear programming problems with examples, Oper. Res. Q. 24 (1) (1973) 65–77, doi:10.1057/jors.1973.9.
[3] F. El Allaki, J. Christensen, A. Vallières, A modified TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) applied to choosing appropriate selection methods in ongoing surveillance for Avian Influenza in Canada, Prev. Vet. Med. 165 (2019) 36–43, doi:10.1016/j.prevetmed.2019.02.006.
[4] C.-L. Hwang, K. Yoon, Multiple Attribute Decision Making (Vol. 186), Springer, Berlin Heidelberg, 1981, doi:10.1007/978-3-642-48318-9.
[5] G. Kim, C.S. Park, K.P. Yoon, Identifying investment opportunities for advanced manufacturing systems with comparative-integrated performance measurement, Int. J. Prod. Econ. 50 (1) (1997) 23–33, doi:10.1016/S0925-5273(97)00014-5.
[6] Mahmoud, Y. M. (2015). Package "topsis" Title TOPSIS method for multiple-criteria decision making (MCDM) Description Evaluation of alternatives based on multiple criteria using TOPSIS method.
[7] M. W. Rosegrant, T.B. Sulser, D. Mason-D'Croz, N. Cenacchi, A. Nin-Pratt, S. Dunston, T. Zhu, C. Ringler, K. Wiebe, S. Robinson, D. Willenbockel, Quantitative foresight modeling to inform the CGIAR research portfolio | IFPRI, Quantitative foresight modeling to inform the CGIAR research portfolio (Project Report for USAID), International Food Policy Research Institute, Washington, 2017 https://www.ifpri.org/publication/foresight-modeling-agricultural-research.

[8] D. Mason-D'Croz, T.B. Sulser, K. Wiebe, M.W. Rosegrant, S.K. Lowder, A. Nin-Pratt, D. Willenbockel, S. Robinson, T. Zhu, N. Cenacchi, S. Dunston, R.D. Robertson, Agricultural investments and hunger in Africa modeling potential contributions to SDG2 – Zero Hunger, World Dev. 116 (2019) 38–53, doi:10.1016/j.worlddev.2018.12.006.

[9] L.G. Ramón-Canul, D.L. Margarito-Carrizal, R. Limón-Rivera, U.A. Morales-Carrrera, I.M. Rodríguez-Buenfil, M.O. Ramírez-Sucre, A. Cabal-Prieto, J.A. Herrera-Corredor, E. Ramírez-Rivera, Technique for order of preference by similarity to ideal solution (<scp>TOPSIS</scp>) method for the generation of external preference mapping using rapid sensometric techniques, J. Sci. Food Agric. jsfa. 10959 (2020), doi:10.1002/jsfa.10959.

[10] H.S. Shih, H.J. Shyur, E.S. Lee, An extension of TOPSIS for group decision making, Math. Comput. Model. 45 (7–8) (2007) 801–813, doi:10.1016/j.mcm.2006.03.023.

[11] V. Yadav, S. Karmakar, P.P. Kalbar, A.K. Dikshit, PyTOPS: A Python based tool for TOPSIS, SoftwareX 9 (2019) 217–222, doi:10.1016/j.softx.2019.02.004.

[12] C.-H. Yeh, A Problem-based Selection of Multi-attribute Decision-making Methods, Int. Trans. Oper. Res. 9 (2) (2002) 169–181, doi:10.1111/1475-3995.00348.