International Journal of Information and Management Sciences
27 (2016), 117-127. DOI:10.6186/IJIMS.2016.27.2.3

International Journal of
Information
and
Management
Sciences

A Generalized PROMETHEE III with Risk Preferences on Losses and Gains

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Abstract

This study aims to generalize the Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE) III model by introducing risk preferences of decision makers. The risk preferences are expressed by an S-shaped value function with gain and loss parts. This study then illustrates an environmental evaluation of waste treatment plants for waste electrical and electronic equipment (WEEE) in Taiwan. Sensitivity analysis and the rank test demonstrate that the proposed model is rather stable.

The PROMETHEE methods have been involved in various applications, especially in environmental management. One core process of PROMETHEE is to establish a preference difference function with two types of thresholds. The range of the slope lines of the linear preference is within the interval of $[0, 1]$. Working from the concept of the prospect theory, we extend its S-shaped function to the interval range of $[-1, 1]$ so as to express risk preferences that occur in two quadrants.

This research assesses a project on 15 local WEEE treatment plants to promote their recycling capability and technology competitiveness. According to the five aspects, the performance measures of the plants are obtained from a field study. The proposed model has an advantage on rank invariance by changing the thresholds in our case with sensitivity analysis demonstrating the robustness of the model. The generalized PROMETHEE III with risk preferences indeed provides an extension for making a decision in an uncertain environment.

Keywords: PROMETHEE, Risk preference, S-shaped value function, Environmental evaluation, Sensitivity analysis.

1. Introduction

Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE) is one type of popular outranking methods in the area of multiple-criteria decision aid (MCDA) for evaluation of actions. It helps decision makers (DMs) to structure, qualify, and analyze real world problems, in order to make a better decision [6]. However, many traditional MCDA methods concentrate on the selection process without considering the risk preferences of DMs. The final choice could thus be distorted in an uncertain environment. To avoid such a distortion, this paper aims to generalize PROMETHEE III through the use of the prospect theory for a behavioral decision. The gains and losses in the process will be accounted for the choice.

PROMETHEE was developed to simplify the well-known ELECTRE method so that the number of its parameters can be reduced and be easily understood by DMs [4]. According to the argument by Téno and Mareschal [20], three advantages can be identified: (i) there is no trade-off between criteria, (ii) it preserves a lot of the decision information, and (iii) it is simple for users. Its outranking relations are formulated by the flows leaving and entering through pair-wise comparisons when considering the indifference and preference thresholds. Six types of practical general criteria or preference difference functions, with the range interval $[0, 1]$, are also defined for ordinary applications. The PROMETHEE family includes PROMETHEE I and II, for partial and complete rankings introduced in the beginning, PROMETHEE III (interval order) and IV (continuous) extensions, PROMETHEE V for constrained multicriteria selection, and PROMETHEE VI for the human brain. Group decision extensions of PROMETHEE have also been developed. In addition, the method has been implemented in software packages to support visual analysis named GAIA (geometrical analysis for interactive aid) [6, 16].

After its introduction over three decades ago, PROMETHEE has attracted great worldwide interest. According to the survey of 217 scholarly papers by Behzadian et al. [2], its applications covers nine areas: (i) environment management, (ii) hydrology and water management, (iii) business and financial management, (iv) chemistry, (v) logistics and transportation, (vi) manufacturing and assembly, (vii) energy management, (viii) social, and (ix) other topics. Among 39 countries, Belgium is the most productive use of it due to its origin. Mareschal [17] presents bibliographical statistics on 1,322 PROMETHEE-related papers, in which there are over 100 publications per year in 2012-2015. In summary, 294 papers (22.2problems and its recent applications, including sustainability assessment [8], geothermal energy planning [18], and tree species ranking in urban environment [22]. The large amount of applications motivates us to explore PROMETHEE and its usage on our environmental problem. Since performance evaluation has some kinds of uncertainties, a technique for manipulating this type of data is worth developing. In the PROMETHEE family, PROMETHEE III seems an appropriate one for our target.

Uncertainty is the fact of life and business. When one establishes a model, there is uncertainty about the estimated parameters, which can be managed by PROMETHEE III. The fuzzy approach for net flows also belongs to this category [20]. The other uncertainty concerns the outside environment as sensed by DMs. When facing this type of uncertainty, DMs attempt to reduce that uncertainty by accepting a certain outcome, but with possibly conservation. This is the risk aversion that is common in human decision making, which is represented by a utility function being concave and showing diminishing marginal utility. It is widespread accepted when consumers and investors are making decisions, but not everyone displays risk aversion all the time. In general, preferences can be classified into three types: risk aversion, risk neutral, and risk seeking [15]. Kahneman and Tversky [14] proposed an S-shaped value function of a descriptive model for catching human behavior. Its two-part power functions illustrate gains and losses, which show risk aversion and risk seeking, respectively. This is useful for the deterministic MCDA [19]. This is another motivation for reflecting gains and losses in PROMETHEE III.

The study is organized as follows. Section 2 illustrates the core of the generalized PROMETHEE III model. Section 3 conducts an evaluation of Taiwan's treatment plants by the proposed model with extra analyses. The final section draws some concluding remarks.

2. Proposed Model

The core process of PROMETHEE is to select a suitable general criterion, which is expressed by six types of preference difference functions [2]. Mareschal [16] mentions that the usual (type I) and level (type IV) functions are best suitable for qualitative criteria, that the U-shaped (type II) function is a special case of the Level one, and that the V-shape (type III) and linear (type V) functions are best eligible for quantitative criteria. The Gaussian function (type VI) or bell shape describes a less favorable value at its center. We observe that the V-shape is the special case of the linear one, which is expressed in Eq. (2.1) and illustrated by Figure 1. Since type V, a linear form, is a general form for quantitative evaluation, the study takes it into account for further development.

When comparing two actions a and b by their evaluations $f(a)$ and $f(b)$, respectively, the preference function $P(a,b)$ is another function of the difference between the two evaluations as follows [5].

$$P(a,b) = \mathscr{P}(f(a) - f(b)) \tag{2.1}$$

To have a better view of the indifference area, a preference difference function is defined as:

$$H(d) = \begin{cases} P(a,b), & d \geq 0, \\ P(b,a), & d < 0. \end{cases} \tag{2.2}$$

Here, $d = f(a) - f(b)$.

The type V linear function $H(d)$ with preference threshold p and indifference threshold q can be depicted as Figure 1 [3]. We can see that the range of the function within the interval $[0,1]$ is due to the setting of Eq.(2.2). This is defined as a special case of the work done by Bouyssou et al. [3]. Following the prospect theory [14], the symmetric form may not be good for decision making that entails risk. An extension on the preference difference function is necessary for any practical decision.

The S-shaped value function of the prospect theory [14] is illustrated as follows.

$$v(x) = \begin{cases} (x-\varphi)^{\alpha}, & \text{if } x \geq 0, \\ (-\lambda)(\varphi - x)^{\beta}, & \text{if } x < 0. \end{cases} \tag{2.3}$$

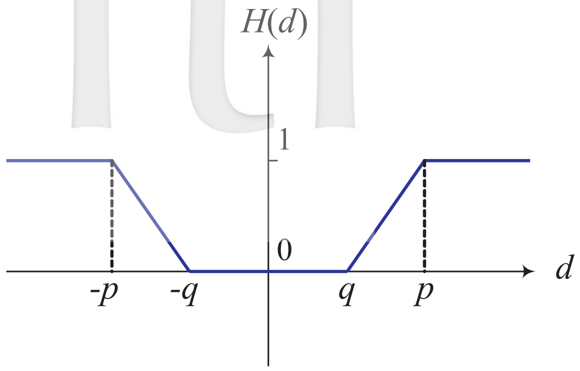

Figure 1: The original type V function.

Here, x is the monetary unit, φ is the reference point, and $\alpha = \beta = 0.88$, $\lambda = 2.25$ originally. The value function that passes through the reference point is S-shaped and asymmetrical. The magnitude of the loss is 2.25 times that of the gain. Wu and Gonzalez [24] propose that $\alpha = \beta = 0.52$ and $\lambda = 2.25$, Abdellaoui et al. [1] recommend that $\alpha = 0.725$, $\beta = 0.717$, and $\lambda = 2.04$, and Xu et al. [25] suggest that $\alpha = 0.37$, $\beta = 0.59$, and $\lambda = 1.51$. To mimic the asymmetric effects in the PROMETHEE preference difference function, in our evaluation we employ Abdellaoui et al.'s recommendation [1] instead of the original one.

The reference point is critical in the prospect theory. In PROMETHEE the evaluations of actions on each criterion are pair-wisely compared that means both actions are relatively referred. If the evaluation $f(a)$ is better than the evaluation $f(b)$, then the preference difference function, or value function $v(f(a) - f(b))$ or $v(d)$ here, will appear at the first quadrant within the interval range $[0, 1]$; otherwise, it will be at the third quadrant within the interval range $[-1, 0]$. Observe that another MCDA technique, TODIM (a Portuguese acronym of Interactive and Multi-criteria Decision Making), also keeps the same style [11].

Based on these concepts mentioned above, we propose the type V preference difference function with risk preference as:

$$H(d) = \begin{cases} 1, & \text{if } d > p, \\ \frac{(d-q)}{(p-q)}, & \text{if } q < d \leq p, \\ 0, & \text{if } -q/l \leq d \leq q, \\ -\frac{d+(q/l)}{(-p+q)/l}, & \text{if } -p/l \leq d \leq -q/l, \\ -1, & \text{if } d > -p/l. \end{cases} \tag{2.4}$$

Here, p and q are preference threshold and indifference threshold, respectively. Parameter l is a tuning factor for risk adjustment, acting as the role of λ in Eq. (2.3); the greater

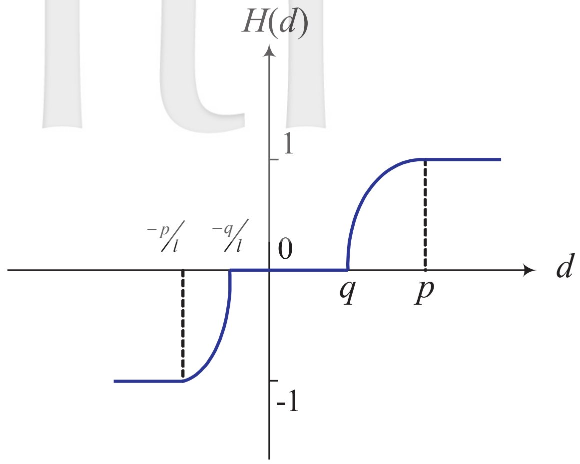

Figure 2: The modified type V function with the highlight of gains and losses.

its value is, the more sensitive the evaluation in the loss part will be. To formulate risk aversion and risking seeking, the second and the fourth parts of Eq. (2.4) are transformed into the two parts of Eq. (2.3). The modified function $H(d)$ is thus:

$$H(d) = \begin{cases} 1, & \text{if } d > p, \\ \left(\frac{(d-q)}{(p-q)}\right)^{\alpha}, & \text{if } q < d \leq p, \\ 0, & \text{if } -q/l \leq d \leq q, \\ -\left(\frac{d+(q/l)}{(-p+q)/l}\right)^{\beta}, & \text{if } -p/l \leq d \leq -q/l, \\ -1, & \text{if } d > -p/l. \end{cases} \tag{2.5}$$

Here, $\alpha = 0.725$, $\beta = 0.717$ and $l = 2.04$. Note that $l = \lambda$ in the modification.

In such a way, these two parts are non-linear and concave down and concave up, respectively. Figure 2 shows the shape of Eq. (2.5), where it mimics the S-shape for the two parts. We now can generalize the PROMETHEE III model with risk preferences on losses and gains. Observe that Eq. (2.5) will be the original linear function form of type V if we set $\alpha = \beta = l = 1$.

Another core work in PROMETHEE III is the uncertainty in parameter estimation for computing the inflow and outflow of actions. The computations are associated with an interval whose range is defined by the upper and lower bounds from the average of net flows, which are from the average plus or minus its deviation times the coefficient γ. The interval is mainly for determining indifference relations. The choice of γ depends on the application, and it is suggested that $\gamma = 0.15$ globally [21]. The greater the value of γ is, the wider the range will be. After the coefficient is set, interval flows are compared and an overlapped part is considered that both are indifference. Following the procedure of PROMETHEE III, the preference and the indifference relations can be explored for the final rankings. We hope our extension can catch behavioral decisions under an uncertain environment.

3. Illustrative Case

To encourage waste recycling for reducing damage to our environment, the Recycling Fund Management Board (RFMB) of the Environmental Protection Administration (EPA) in Taiwan was initialized in 1998. It collects funds from manufacturers and importers and monitors the flow of waste materials through monetary subsidies to the recycling industry and others [10]. Since hazardous materials are a major concern [23]. RFMB has pushed the recycling of electronics products since 2001. After a decade of policy implementation through a flat subsidy rate, RFMB is now consider whether some basic goals have been achieved, e.g., maintaining good recycling behavior and a well-developed environmental education. There is still a chance to further promote the recycling capability and competitiveness of the treatment plants in the waste electrical and electronic equipment (WEEE) recycling industry in Taiwan. Another project for the evaluation of WEEE treatment plants is being executed. The purpose of the project is to rank and classify 15 local plants by their performance indices. RFMB will offer an extra subsidy rate if a plant's performance is above the standard; RFMB will provide lower rates if a plant's performance is fair or not well. RFMB will also force those plants performing below the standard to improve their recycling capability [7].

RFMB first established feasible rating indicators based on the concept of Electronic Product Environmental Assessment Tool (EPEAT) [12] and from the guidance of ISO 14030 Standard [13]. There are 43 indicators grouped into five aspects: environment protection, management system, financial performance, technology achievement, and social responsibility.

- Environment protection: for regulatory compliance, waste process examination, and contaminant collection.
- Management system: for operations quality, plant worker and environment, and international certifications of OHSAS 180001, ISO 14064, and EN 16001/ISO 50001.
- Financial performance: for financial information disclosure, operations efficiency, the ability to repay debt, profitability, and company size.
- Technology achievement: for compliance of waste processing specifications, advanced resource recycling potential, and integration of reverse logistics chain.
- Social responsibility: for corporate social responsibility, establishment of recycling depots, and efforts made on corporate social image.

Table 1 lists the performance data of these 15 plants by each aspect. There are three stakeholders in the group of the decision makers: an expert from RFMB, a scholar from the related department of a local university, and a plant representative. The weights on the five aspects by the group are given as 0.25, 0.25, 0.15, 0.25, and 0.1, respectively.

Table 1: Performance measures of the E-waste treatment plants by five aspects.

Plant	Aspect				
	Environmental protection	Management system	Financial performance	Technology achievement	Social responsibility
A	3.75	5.5	7.5	6.3	2.0
B	3.75	5.1	7.5	6.3	3.0
C	4.25	4.75	8.5	7.6	3.5
D	3.25	5.0	5.25	2.2	1.0
E	3.25	5.5	6.0	4.6	1.0
F	4.25	5.1	7.0	6.1	2.8
G	2.75	1.3	6.6	3.9	1.3
H	3.95	3.8	7.35	2.6	1.5
I	2.8	4.55	7.1	4.1	2.5
J	3.85	6.75	7.0	5.3	4.3
K	4.1	4.0	5.6	8.6	2.0
L	3.25	2.75	6.8	4.1	1.0
M	4.25	5.5	5.05	5.9	2.0
N	3.25	4.75	6.6	3.6	4.0
O	2.8	3.5	6.6	4.6	3.0

Table 2: The proposed values of five cases on their thresholds.

Case	Thresholds					
		Environmental protection	Management system	Financial performance	Technology achievement	Social responsibility
I	indifference q	0.10	0.10	0.10	0.10	0.10
	preference p	0.25	0.30	0.25	0.30	0.30
II	indifference q	0.20	0.25	0.20	0.25	0.25
	preference p	0.50	0.60	0.50	0.60	0.60
III	indifference q	0.30	0.40	0.30	0.40	0.40
	preference p	0.60	0.80	0.60	0.80	0.80
IV	indifference q	0.40	0.60	0.40	0.60	0.60
	preference p	0.80	1.20	0.80	1.20	1.20
V	indifference q	0.50	0.80	0.50	0.80	0.80
	preference p	1.00	1.60	1.00	1.60	1.60

Since the thresholds are critical for PROMETHEE, we set five cases for the preference and indifference thresholds from narrow to wide ranges. Table 2 presents the thresholds of these five cases.

Table 3: Ranks of alternatives for the five cases.

Model	Case	Alternatives															Note
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
Proposed	I	2	2	1	13	8	2	15	9	11	2	7	13	6	10	12	8 ranks unchanged
	II	2	2	1	13	8	2	15	9	9	2	7	13	6	9	12	
	III	2	2	1	13	8	2	15	9	9	2	7	13	6	9	12	
	IV	3	3	1	13	9	3	15	9	9	2	7	13	6	8	12	
	V	3	3	1	13	9	3	15	9	9	2	6	13	6	8	12	
Traditional	I	2	2	1	13	8	2	15	9	11	2	7	13	6	10	12	6 ranks unchanged
	II	2	2	1	13	8	2	15	10	10	2	7	13	6	8	12	
	III	3	3	1	13	9	3	15	9	9	2	7	13	6	8	12	
	IV	3	3	1	13	9	3	15	11	9	2	6	13	6	8	11	
	V	3	3	1	13	9	3	15	11	9	2	6	13	6	8	11	

Since a large value for the interval range on the indifference threshold, e.g., $\gamma = 0.15$, will cause no difference on the alternatives, we set the value to be 0.05 for this case study. Table 3 presents the analytic results of the proposed model by the five cases. Based on the evaluation, Plants A, B, C, F, and J are categorized as first class and thus are recommended to obtain a better recycling subsidy; Plants E, H, I, K, M, and N are grouped as second class and can keep the current subsidy; and Plants D, G, L, and O are classified as third class, thus demoted to a lower subsidy as a form of penalty and need to improve their treatment capability.

To determine the effects of the values of the weights of criteria on the final results, we execute a sensitivity analysis. The target weight is on the aspect of environmental protection, which is more important and currently is 0.25. The value is sequentially changed by increasing and decreasing by 10%$-$50%. Table 4 shows the results of Case III, where we can see that they are rather stable, especially for the first-class plants.

After proposing a risk preference model for PROMETHEE III and analyzing an environmental evaluation case, we now further compare the results from the traditional PROMETHEE III model. The first work is to execute a Spearman rank test [9] on both methods in order to ensure their correlation. Based on the ranks generated by both methods, their correlation coefficient is 0.9803 in Case III. The relationship between the methods is very close, as the value is approaching to 1, which means that we cannot tell the difference between both methods in our case since they possess some common features. However, by examining the ranks' invariance of the five cases in Table 2, we know that the proposed model performs better than the traditional one, because eight ranks remain unchanged instead of six ranks being unchanged. The introduction of the loss part in PROMETHEE III has an edge over the alternative ranking.

Table 4: Sensitivity analysis on changing the weight of environmental protection.

Change	Alternatives															Note
of weight	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
50%	4	4	1	13	9	2	15	8	11	3	7	12	4	9	12	
40%	4	4	1	13	8	2	15	8	11	3	7	12	4	8	12	
30%	4	4	1	13	8	2	15	8	11	2	7	12	4	8	12	
20%	2	5	1	13	8	2	15	8	11	2	7	13	5	8	12	
10%	2	2	1	13	8	2	15	10	10	2	7	13	6	8	12	
0%	2	2	1	13	8	2	15	9	9	2	7	13	6	9	12	Original weight
10%	2	2	1	13	8	2	15	9	9	2	7	13	6	9	12	
20%	2	2	1	13	8	2	15	11	10	2	7	13	6	9	11	
30%	3	3	1	13	8	3	15	11	10	2	7	13	6	9	11	
40%	3	3	1	13	8	3	15	11	8	2	7	13	6	8	11	
50%	3	3	1	13	8	3	15	11	8	2	6	13	6	8	11	

5. Concluding Remarks

In this study we have proposed a generalized PROMETHEE III with risk preferences on losses and gains and applied it to an environmental evaluation. Due to the ability at processing interval values, PROMETHEE III is able to deal with the problem of uncertainty on parameter estimation. The new model enhances its capability for handling risk preferences of decision makers. Through the case study, the proposed model demonstrates an edge in ranks invariance after data evaluation.

The selection of the values for the preference and indifference thresholds is crucial for PROMETHEE analysis. There is no straightforward guideline for selecting a suitable value. In general, the values of indifference thresholds should be less than the values of preference thresholds, and the latter should be less than the range of the criterion. In this study we take advantage of the five cases by taking the value from a small set and gradually moving it to a large set to cover any possible variation. Technically, the values are set around 5% to 10% for the range of the criterion.

One benefit of PROMETHEE III is processing interval data that are controlled by the coefficient γ. Though it is suggested that $\gamma = 0.15$ for common use, this seems too loose for our case. This value generates more indifference alternatives, thus causing the discrimination problem.

There are many sets of values for the parameters of an S-shaped value function suggested by the past works. We have not yet executed experiments for obtaining the appropriate parameters in our environmental evaluation. This could be left for future study.

Acknowledgement

The research behind this paper was partially supported by the Ministry of Science and Technology, Taiwan, ROC under grant number NSC 102-2221-E-032-025-MY2. Special thanks are given to Professor Yves De Smet at Université Libre de Bruxelles, Belgium for his valuable help.

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(Received Apr 2016; accepted May 2016)