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Abstract

At present, the per capita generation of solid waste in Malaysia varies from 0.45 to 2kg/day depending on the economic status of an area. In general, the per capita generation rate is about 1kg/day. Even though 17,000 tonnes/day of solid waste is being generated, only 5% is being recycled. If this particular scenario continues without appropriate mitigation, Malaysia will be facing a serious problem in municipal solid waste management. Hence, government has targeted 22% of waste to be recycled by 2020. Various strategies have been formulated in achieving this figure.

In Malaysia, research is being done vastly on recycling but very few related to multicriteria. As a first step, we propose here an evaluation of various recycling strategies and ranking them based on multicriteria to provide an insight on increasing the recycling activities among residents. Since values of alternatives are imprecise, ambiguous and/or uncertain, the multicriteria outranking analysis is particularly useful in order to facilitate further detailed consideration. The problem of the selection or the ranking of alternatives submitted to a multicriteria evaluation is not an easy problem economically or mathematically. We propose a modified PROMETHEE analysis for treating multicriteria problems.

JEL Classification: C44, C61, Q53

Keywords: solid waste management, recycling, multicriteria decision-aid (MCDA), PROMETHEE, outranking relations

1 Introduction

The rapid growth in the urban population due to rural-urban migration and natural growth as well as changing consumption patterns contributed to an increase in the generation and composition of solid waste. The estimated amount of waste generated by the urban population in 2000 was 11,940 tonnes per day or 0.8 kilogram per capita per day(EPU,2001). This large amount of solid waste strained existing landfill sites, and the majorities of disposal grounds were considered unsanitary landfills or merely open dumps.

The problem was compounded by cases of open burning being reported at dumpsites. To ensure a more efficient waste management system, the privatization of solid waste management was started on an interim basis. Two of the four consortia involved started collection of solid waste in 26 of the 145 local authorities by the end of the plan period. As a whole, a total of 23 municipal disposal sites were upgraded to ensure proper disposal. The government also conducted awareness campaigns to encourage the reduction, reuse and recycling of waste materials.

In the Seventh Malaysia Plan (1995-2000), the Malaysian government introduced a new law on solid waste management. In general, the principal processes options available and being recognized as hierarchy for integrated waste management are listed as follows: waste minimization, reuse, material recycling, energy recovery and landfill. During the Eighth Malaysian Plan (2001-2005) period, government will consider the adoption of a comprehensive waste management policy to address issues of waste reduction, reuse and recycling (EPU, 2001).

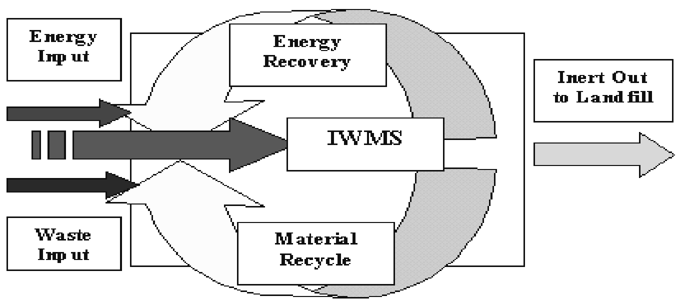


Figure 1: **An integrated waste management system**

Source: Integrated Waste Management and Thermal Oxidation Plant(MINT: NST Quaterly, 2000)

An integrated waste management system (Figure 1)would include waste collection and sorting, followed by one or more of the following :

1. Waste reduction and recovery of secondary materials (recycling): this will require adequate sorting and access to reprocessing facilities.

2. Biological treatment of organic materials: this will produce marketable compost or reduce volume for

disposal. Anaerobic digestion produces methane that can be burned to release energy.

3. Thermal treatment: this will reduce volume, render residues inert and may recover energy.

4. Landfill: this can increase amenity via land reclamation but will at least minimize pollution and loss of amenity.

The purpose of the paper is to analyze various recycling strategies in order to increase recycling of Municipal Solid Waste (MSW) by the year 2020. In achieving the above objective, we have enlisted two sub-objectives:

1. increase the awareness among people/ educate them on recycling and the benefits

2. increase the infrastructures related to recycling

In this paper, we propose a multicriteria evaluation of alternatives, followed by ranking to provide an insight to the decision makers on which alternative/s they should focus in achieving the objective. First, we will look at the present scenario of solid waste management and recycling in Malaysia. Next, we will examine various criteria and recycling strategies for evaluation. In section 3, we propose a modified PROMETHEE analysis to deal with outranking relation with discordance. In section 4, we will further analyze and rank the recycling strategies using this approach. Lastly, we conclude with a few recommendations.

2 Formulation of Problem

Malaysians generate about 72% compostable waste, comprising organic waste, paper, textile/leather and wood. The amount of plastic waste accounts for 16% and is considered very high and is typical of a fast developing nation. The amount of solid waste generated shows an increasing trend (Table 1). An average annual generation rate increase of 4% is predicted (2.5% attributed to population increase, 1.5% due to increase of waste production per capita). It has been estimated that the average Klang Valley resident produced 1.56kg of garbage every day in 1998 (The Star, 2000), enough to fill all 88 floors of the Twin Towers in nine days.

TABLE 1: SOLID WASTE GENERATED, 1996-2000 ('000 tonnes)

Area	1996	1997	1998	1999	2000*
Kuala Lumpur	na	na	1058	1070	1082
Selangor	na	na	1169	1204	1240
Pahang	na	na	202	206	210
Kelantan	na	na	123	126	129
Terengganu	na	na	119	122	125
Negeri Sembilan	245	250	267	278	291
Malacca	192	200	208	216	225
Johore	854	890	927	956	1005
Perlis	26	27	28	28	29
Kedah	507	538	569	560	631
Penang	570	591	611	630	648
Perak	672	696	719	741	736
Total	3066	3192	6000	6137	6378

Source: Eight Malaysian Plan 2001-2005, EPU, 2001.

Note:* Estimates, n.a.= not available

The generation of solid wastes presents challenges to solid waste managers and town and country planners, due to lack of available landfill space, and also because solid waste management represents every significant increases in collection and disposal facilities and functions, which will affect the manpower needed to manage them. The majority of dump sites in Malaysia have no leachate or gas management facilities, and no daily earth covering of the piles, so they are leaching chemicals into the groundwater, poisoning the air with toxic gases and generally being health hazards. To compound the problem, most of the dumpsites are almost full.

Collection methods and landfills

Waste collection involves the gathering of waste by collection trucks that transport it to intermediate processing plants, transfer stations or landfills. Collection is the most expensive activity and is both capital-and labor-intensive, accounting for some 60-75% of the cost of waste management (Nasir et. al, 1998). In Malaysia, the most widely-practiced collection methods are the door-to-door front curbside method, for accessible households, while for the relatively inaccessible areas, collection is from communal bins.

After collection, most wastes are transported to landfills. There are 230 official dumping sites in Malaysia, the majority of which are crude landfills, with only 10% providing leachate treatment ponds and gas ventilation systems and with most having no control mechanisms and supervision (Zaman, 1992). Steps are being taken to upgrade the landfills, and this includes fence installation, weighbridge and site-office wheel washing troughs, and gas disposal pipes.

In almost all landfills, there are sorting activities by scavengers for cardboard, plastics, bottles and metals, with the remaining pile levelled by bulldozers. At the end of the day, the pile is supposed to be covered by a layer of soil and compacted to reduce infestation by vermin (flies, rats, birds), fire and odor problems, although this is frequently not done.

Waste management hierarchy and 3R

Presently, about 17,000 tonnes of solid waste is being discarded daily, of which only 70 percent is collected and disposed. The remaining 30 percent is either disposed of illegally or is recycled. However, it is estimated that only about 5% is being recycled. The waste management hierarchy (Figure 2) states that wastes should be prevented or reduced at the source whenever feasible and safe disposal is the option of last resort.

Source reduction or waste prevention, which includes reuse, is the best approach, followed by recycling. Waste that cannot be prevented or recycled can be incinerated or landfilled according to proper regulations. Source reduction at the top of the hierarchy because the best approach to managing solid waste is to avoid creating it in the first place. This means reducing the amount of trash being discarded and reusing containers and products instead of throwing them away. Once waste is created, recycling, which includes composting, is one of the most effective methods of reducing the amount of material in the waste stream. If waste cannot be recycled, incineration or sanitary landfilling are the next preferred methods of treatment.

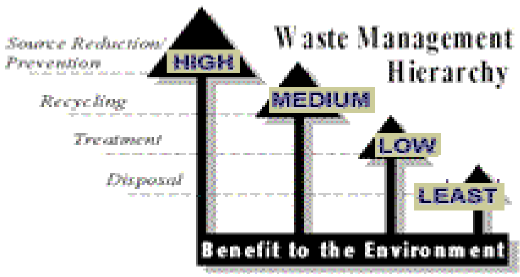


Figure 2: **The waste management hierarchy**

Source: US Environmental Protection Agency website

Why Recycle?

With 17,000 tonnes of rubbish produced everyday, it is only a matter of time before we run out of space to dispose of them. Recycling reduces waste, which in turn reduces the need for landfills and dumpsites. Recycling reduces pollution and saves energy. Making products from virgin or raw materials results in pollution and uses more energy. Recycling is cheaper in the long run compared to maintaining landfills and other systems. When recycling programmes become more efficient, there will be less rubbish to dispose of. Recycling creates up to 5 times more jobs than waste disposal alone. It will create jobs for engineers, machine specialists, environmental personnel, general workers and many more. Recycling improves cleanliness and quality of life. Breakdown of solid waste created by Malaysians are as shown in Table 2.

Table 2: Breakdown of Solid Waste

Types	percentage %
Paper	27%
Household waste	36.5%
Steel	3.9%
Glass	3.7%
Plastic	16.4%
Others	12.5%

Source:www.kitarsemula.com

Experts believe a landfill can last 10 years longer if Malaysians recycled 50% of their garbage. Recycling of solid wastes, especially the non-combustible waste (glass and metal); combustible but hazardous waste (plastic) and paper, reduces the amount of waste introduced into the environment and the need for disposal capacity. The benefits of recycling are two-hold. Firstly, recycling cuts down the need for disposal capacity, lowers emission from landfills and incinerators and reduces litter. Secondly, the use of recycled materials in industries reduces energy use and emissions; lessens impacts when raw material is extracted or manufactured and conserves raw materials (Agamuthu, 2001).

However, three important elements of integrated solid waste management hierarchy (source reduction, waste recycling and waste transformation) are not officially and legally incorporated into the Malaysian waste management practice. In the year 2000, the Malaysian government has targeted 22% of waste to be recycled by the year 2020. Various strategies are being formulated in achieving this figure. These strategies form a guideline for all local authorities in implementing the recycling program.

Recycling alternatives and multi-criteria for consideration

Alternatives/ Action plans

The Ministry of housing and local authorities of Malaysia has outlined several existing action plans to increase the recycling activities throughout the nation. These alternatives have been divided into two main groups; awareness creation program and increasing infrastructure program. With the outline given by ministry, each local authority can act independently to achieve the recycling objective.

Group 1: awareness creation program (66% of government budget allocation for recycling)

Under this program, there are 5 alternatives/action plans to increase awareness among the public. The alternatives are as listed below. We propose an evaluation to derive a proposal on which one of this action plan/s can contribute in increasing the awareness among the public.

1. Billboard advertisement (a_1)
2. Carnival, exhibition and briefing (a_2)
3. Printed matters: posters, pamphlets and bulletins (a_3)
4. Electronic medium; television, radio, websites (a_4)
5. Transportation (a_5): consists of
   - public transportation such as light rail transit (LRT), commuters, public bus
   - school bus

Group 2: increase the infrastructure program: recycling-friendly facilities (29% of government budget allocation for recycling)

Under this program, 5 alternatives/ action plans has been formulated. Some have been practiced longer than others.

1. Recycling bin (b_1): 240 Lt, 360 Lt, 660Lt; - 7080 units of 240Lt and 3675 units of 360Lt bins are located at public places all over Malaysia - 3950 units of 660Lt is located at collection centers
2. Silverbox (b_2): only 44 units are distributed to some of the local municipalities/ city councils as Silverboxes are costly
3. Recycling Lorry (5 tonne)(b_3): to collect recyclable items from collection center, schools, residential association, kerb side collection
4. Recycling van (b_4): house to house collection (on-call basis)
5. Recycling center/Collecting centers(b_5): there are 718 collection centers to enable residents to bring the recyclable items. More are being built. However, there are only a limited number of recycling center.

We propose an evaluation of these alternatives to provide an understanding on how to encourage the public to recycle by answering the following question:

- is it achieved by providing/ placing more recycling bins in a way that the public cannot avoid but utilize it?
- is it achieved by having lesser bins but provide more collection vehicles?
- is it achieved by having more recycling/ collection centers at every residential area (every "Taman")?

The best method to answer these questions is the evaluation based on multicriteria.

Decision makers/Stakeholders

Decision makers are the local authorities and city councils. However, the ranking of these plans vary according to the stakeholders and their interest. In this paper, we concentrate our analysis and rank the recycling alternatives focusing on the local authorities and city councils as the decision maker. However, there are many other stakeholders with different interest in recycling. Ranking of alternatives depend on these stakeholders and their objectives. The stakeholders are the education institutions, NGO's, concessionary companies, recyclable waste collectors and association, residence association, private sector: corporate, shopping malls, restaurants and others [hotels, hospitals, religious institutions].

Criteria for consideration

From the interview with the government officers involved in recycling in Malaysia, we have listed some of the criteria for consideration:

1. cost (c_1)
2. maintenance (c_2)
3. efficiency (c_3)
4. targeted result (c_4)

These criteria can further be described:

1. Cost refers to all the cost directly involved in starting the strategy such as planning and engineering and cost of the equipments and building. Cost is a minimizing objective. A higher score is more desirable than a lower one. We use the following score:

Category	Score
Low	5
Relatively low	4
Fair	3
Relatively high	2
High	1

2. Maintenance refers to the maintenance and operational cost of each action (includes cost of employing workers): a score of 1 - 5 indicate the degree of maintenance cost:

Degree	Score
low maintenance cost	5
relatively low maintenance cost	4
fair maintenance cost	3
relatively high maintenance cost	2
high maintenance/ continuous maintenance cost	1

3. Efficiency: refers to the efficiency of each plan to date. The score is between 1 (0% - 20%) and 5 (80% - 100%).

Rating	Score
80% - 100%	5
60% - 80%	4
40% - 60%	3
20% - 40%	2
0% - 20%	1

4. Targeted result: This target refers to the expected result from each action plan and is given in percentage.

The following table presents a summary of the alternatives and criteria for consideration:

Group 1: Creating awareness

Alternatives/criteria	Cost (c_1) (min)	Maintenance (c_2) (min)	Efficiency (c_3) (max)	Target (c_4) (max)
Billboard Advertisement (a_1)	1	1	2	50%
Carnival , exhibition, briefing (a_2)	2	3	3	70%
Printed matters (a_3)	3	4	2	40%
Electronic media (a_4)	1	2	4	80%
Transportation (a_5)	2	2	3	60%

Group 2: Recycling facilities

Alternatives/criteria	Cost (c_1) (min)	Maintenance (c_2) (min)	Efficiency (c_3) (max)	Target (c_4) (max)
Recycling bin (b_1)	3	2	3	40%
Silverbox (b_2)	3	2	2	20%
Recycling Lorry (b_3)	1	3	4	60%
Recycling Van (b_4)	2	3	5	80%
Recycling/ collection center (b_5)	1	1	2	50%

3 PROMETHEE Multiple Criteria Analysis

The outranking analysis has been frequently used to deal with the complex decisions involving quasi-criterion and pseudo-criterion (see Roy and Vincke, 1984, Vincke, 1992). So far, PROMETHEE (Preference Ranking Organization METHod for Enriching Evaluations)have been proposed for the outranking analysis(see Brans and Vincke, 1985). PROMETHEE methods have taken an important place among the existing outranking multicriteria methods (Keyser and Peeters, 1996). A particularly user-friendly *Decision Lab* software makes it easier to conduct the PROMETHEE analysis. PROMETHEE is based on the positive (out-) and negative (in-) preference flows for each alternative in the valued outranking relation to elicit the ranking of alternatives according to the decision maker's preferences. The positive flow is expressing how much an alternative is dominating the other ones, and the negative flow how much it is dominated by the other ones. Based on the preference flows, PROMETHEE I provides a partial preorder. PROMETHEE II is also introduced to obtain a complete preorder by using a net flow, though, it loses much information of preference relations (see Brans, and Mareschal, and Vincke, 1986). It is not possible to take discordance into account when constructing the outrank relations of PROMETHEE (Keyser and Peeters, 1996). Discordance is however considered as a realistic concept in multiple criteria decision aid and is considered as one of the reasons for developing outranking methods (Vincke, 1992).

In this paper, we propose a modified procedure using the "weighted" preference flows to get a partial preorder in a PROMETHEE context. It reduces to the eigenvalue problem. An advantage of the modified procedure is that the ranking of alternatives is relatively stable in the change of components in the outranking relation matrix. Therefore, it is useful for the outranking relations which take discordance into account.

Let us consider the set A of n alternatives:

$$A = \{\boldsymbol{a}_i, \boldsymbol{a}_2, \ldots, \boldsymbol{a}_n\}.$$

Let $g_1, g_2, \ldots, g_m$ be m-criteria. Thus, each alternatives $\boldsymbol{a}_i$ is characterized by a multiattribute outcome denoted by a vector

$$(g_1(\boldsymbol{a}_i), g_2(\boldsymbol{a}_i), \ldots, g_m(\boldsymbol{a}_i)) .$$

The valued outranking relation is constructed from the notions of quasi-criterion and pseudo-criterion. In particular, PROMETHEE constructs it using a preference function which represents the decision maker's preference for an alternative $\boldsymbol{a}_i$ with regard to $\boldsymbol{a}_j$. Several types of preference functions are considered for the criteria such as usual criterion, quasi-criterion, criterion with linear preference, level criterion, pseudo-criterion with linear preference and indifference area, and Gaussian criterion (see, Brans and Vincke, 1985 and Brans, and Mareschal, and Vincke, 1986). To be precise, let

$$P_k(\boldsymbol{a}_i, \boldsymbol{a}_j) = f\left[g_k(\boldsymbol{a}_i) - g_k(\boldsymbol{a}_j)\right]$$

be the preference function associated with the criterion $g_k(\cdot)$. As $f(\cdot)$, six types of functions are proposed to cover most of the cases in practical applications. Then, the valued outranking relation $\pi(\boldsymbol{a}_i, \boldsymbol{a}_j)$ of $\boldsymbol{a}_i$ over $\boldsymbol{a}_j$ is defined as the weighted sum of the preference functions P_k:

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_j) = \sum_k P_k(\boldsymbol{a}_i, \boldsymbol{a}_j) w_k,$$

where w_k is a weight for criterion k. Thus, $\pi(\boldsymbol{a}_i, \boldsymbol{a}_j)$ represents the intensity of the preference of $\boldsymbol{a}_i$ over $\boldsymbol{a}_j$ for all the criteria: the closer to 1, the greater the preference. We now introduce the weighted sum of preference (out-) flows.

$$\lambda \psi^+(\boldsymbol{a}_i) = \sum_{j=1}^{n} \pi(\boldsymbol{a}_i, \boldsymbol{a}_j) \psi^+(\boldsymbol{a}_j), \qquad i = 1, 2, \ldots, n, \tag{1}$$

where λ is a constant.

This implies that, if $\boldsymbol{a}_i$ outranks $\boldsymbol{a}_j$ having a high value of $\psi^+(\boldsymbol{a}_j)$, it should reflect a higher attractiveness than $\boldsymbol{a}_i$ over $\boldsymbol{a}_j$ having a low value of $\psi^+(\boldsymbol{a}_j)$.

Similarly, we define the weighted sum of preference (in-) flows

$$\lambda \psi^-(\boldsymbol{a}_i) = \sum_{j=1}^{n} \pi(\boldsymbol{a}_i, \boldsymbol{a}_j) \psi^-(\boldsymbol{a}_j), \qquad i = 1, 2, \ldots, n, \tag{2}$$

Thus, using the weighted sum of preference flows reduces the eigenvalue problem:

$$\Pi \boldsymbol{\psi}^+ = \lambda \boldsymbol{\psi}^+ \tag{3}$$

$$\boldsymbol{\psi}^- \Pi = \lambda \boldsymbol{\psi}^- \tag{4}$$

where $\Pi = (\pi(\boldsymbol{a}_i, \boldsymbol{a}_j))$, $\boldsymbol{\psi}^+ = (\psi^+(\boldsymbol{a}_i))$ and $\boldsymbol{\psi}^- = (\psi^-(\boldsymbol{a}_i))$.

In what follows, to assure that the eigenvectors $\boldsymbol{\psi}^+ = (\psi^+(\boldsymbol{a}_i))$ and $\boldsymbol{\psi}^- = (\psi^-(\boldsymbol{a}_i))$ corresponding to the maximum eigenvalue of any valued outranking relation have positive components, for calculation, we replace $\pi(\boldsymbol{a}_i, \boldsymbol{a}_j) = 0$ by $\pi(\boldsymbol{a}_i, \boldsymbol{a}_j) = \varepsilon$ where ε is a sufficiently small positive number.

Theorem. *If the outranking relation $\Pi = (\pi(\boldsymbol{a}_i, \boldsymbol{a}_j))$ is a complete preorder, $\psi^+(\cdot)$ and $-[\psi^-(\cdot)]$ are strategically equivalent value functions which represent the decision maker's preferences.*

Proof: see Appendix

4 A Modified PROMETHEE Analysis of the Recycling Strategies

Setting weights

Weights are set based on the interview with several government officials involved in recycling in Malaysia. From these officials point of view, cost criteria is more important than all other criteria as all local authorities have to formulate their strategies within the budget allocated to them. With PROMETHEE, no specific guidelines are provided to determine the weights. PROMETHEE assumes that the decision-maker is able to weigh the criteria appropriately, at least when the number of criteria is not too large. This may be difficult to to achieve by an inexperienced user. Macharis (2004) suggested to utilize Analytic Hierarchy Process (AHP). From the interview, we constructed the following reciprocal matrix:

	c_1	c_2	c_3	c_4
c_1	1	E	B(W-S)	B(D-S)
c_2	1/E	1	B(W-S)	S
c_3	1/B(W-S)	1/B(W-S)	1	B(W-E)
c_4	1/B(D-S)	1/S	1/B(W-E)	1

*E=equal, W=weak, S=strong, D=demonstrated, A=absolute, B(.-.)between values indicated in parentheses.

From this, the priority vector is derived:

(0.422, 0.397, 0.081, 0.1).

From this priority vector, we find that the cost criteria (c_1) is more important, followed by the maintenance criteria (c_2), target (c_4) and efficiency (c_3). $\lambda_{max} = 4.1327$, C.I.=0.043, thus, a consistency ratio (C.R.) of 0.048 (≤ 0.1) is considered acceptable.

Group1: Creating Awareness

As for alternatives, we have the following ,

criteria		c_1	c_2	c_3	c_4
weight (w_i)		0.422	0.397	0.081	0.1
alternatives	$\boldsymbol{a}_1$	1	1	2	50
	$\boldsymbol{a}_2$	2	3	3	70
	$\boldsymbol{a}_3$	3	4	2	40
	$\boldsymbol{a}_4$	1	2	4	80
	$\boldsymbol{a}_5$	2	2	3	60

Since, scores are imprecise and ambiguous, we employ the outranking method. Therefore, it is important to determine the preference (p), indifference (q) and veto (v) thresholds. It is as given in the table below.

Threshold	c_1	c_2	c_3	c_4
p	2	2	2	20
q	1	1	1	10
v	10	10	10	100

From this, we have an outranking relation matrix.

$$\begin{array}{c} \\ \boldsymbol{a}_1 \\ \boldsymbol{a}_2 \\ \boldsymbol{a}_3 \\ \boldsymbol{a}_4 \\ \boldsymbol{a}_5 \end{array} \begin{array}{c} \begin{array}{ccccc} \boldsymbol{a}_1 & \boldsymbol{a}_2 & \boldsymbol{a}_3 & \boldsymbol{a}_4 & \boldsymbol{a}_5 \end{array} \\ \begin{pmatrix} 1 & 0.503 & 0.181 & 0.819 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 0.9 & 1 & 0.819 & 0.9 \\ 1 & 1 & 0.181 & 1 & 1 \\ 1 & 1 & 0.603 & 0.9 & 1 \end{pmatrix} \end{array}$$

From a modified PROMETHEE, we have:

$\psi^+ = (0.676, 1, 0.922, 0.825, 0.896)$

$\psi^- = (1, 0.872, 0.547, 0.912, 0.987)$

$\lambda_{max} = 4.318$

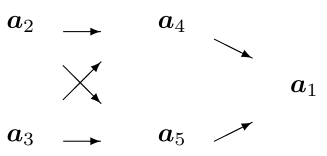
Descending:

$a_2 \rightarrow a_3 \rightarrow a_5 \rightarrow a_4 \rightarrow a_1$

Ascending:

$a_3 \rightarrow a_2 \rightarrow a_4 \rightarrow a_5 \rightarrow a_1$

and thus:



Interpretation of the result:

From the ranking, alternatives a_2 (carnival, exhibition, briefing) and a_3(printed matters) are preferred to the rest. These two alternatives contributes more in creating awareness among the public. The local authorities organize exhibitions at well-known shopping complexes during the 'Environment Week' or some other events. One of the television station, TV3, organized a carnival to create awareness among the public. Usually during such events, the organizers incorporate other features to attract the crowd. For example, during 'Environment Week', they organize 'treasure hunt', various contest to attract the children and medical check-ups for a minimum fee. Some events emphasizes the need for recycling directly, while others, indirectly. The posters on the need to recycle and other information related to recycling are usually found at all public spots.

Alternative (a_1) is the least preferred. From the analysis, we find that billboard advertisement contribute less in creating awareness among the public. Furthermore, it involves very high initial cost and maintenance cost. So far, the efficiency is quite low. Electronic media and transportation contribute less but are better alternative in increasing awareness compared to billboard advertisement.

Group 2: Recycling Facilities

As for alternatives, we have the following ,

criteria		c_1	c_2	c_3	c_4
weight (w_i)		0.422	0.397	0.081	0.1
alternatives	$\boldsymbol{b}_1$	3	2	3	40
	$\boldsymbol{b}_2$	3	2	2	20
	$\boldsymbol{b}_3$	1	3	4	60
	$\boldsymbol{b}_4$	2	3	5	80
	$\boldsymbol{b}_5$	1	1	2	50

The preference (p), indifference (q) and veto (v) thresholds are as given in the table below.

Threshold	c_1	c_2	c_3	c_4
p	2	2	2	20
q	1	1	1	10
v	10	10	10	100

From this, we have an outranking relation matrix:

$$\begin{array}{c} \\ \boldsymbol{b}_1 \\ \boldsymbol{b}_2 \\ \boldsymbol{b}_3 \\ \boldsymbol{b}_4 \\ \boldsymbol{b}_5 \end{array} \begin{array}{c} \begin{array}{ccccc} \boldsymbol{b}_1 & \boldsymbol{b}_2 & \boldsymbol{b}_3 & \boldsymbol{b}_4 & \boldsymbol{b}_5 \end{array} \\ \begin{pmatrix} 1 & 1 & 0.9 & 0.819 & 1 \\ 0.9 & 1 & 0.819 & 0.819 & 0.9 \\ 0.578 & 0.578 & 1 & 0.9 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 0.578 & 0.578 & 0.522 & 0.422 & 1 \end{pmatrix} \end{array}$$

From a modified PROMETHEE, we have:

$\psi^+ = (0.938, 0.887, 0.793, 1, 0.589)$

$\psi^- = (0.814, 0.834, 0.851, 0.791, 1)$

$\lambda_{max} = 4.207$

Descending:

$b_4 \to b_1 \to b_2 \to b_3 \to b_5$

Ascending:

$b_4 \to b_1 \to b_2 \to b_3 \to b_5$

and thus:

$$\boldsymbol{b}_4 \longrightarrow \boldsymbol{b}_1 \longrightarrow \boldsymbol{b}_2 \longrightarrow \boldsymbol{b}_3 \longrightarrow \boldsymbol{b}_5$$

Interpretation of the result:

In Group 2, we evaluate 5 strategies on how to increase recycling among the residents by providing the necessary infrastructure. From the ranking, alternatives b_4 is preferable to alternatives b_1, b_2, b_3 and b_5. Recycling van is preferred to other alternatives. Recycling lorry is the fourth mode that can initiate interest of recycling among the residents. Recycling van is more effective in increase the recycling interest among the residents because residents can call for this van to collect the recyclable items. Whereas, the recycling lorry is available only on certain days for certain areas.

Recycling center is the least preferred because most center are away from individual housing units and residents prefer if the segregated waste are collected from house to house. Apart from the recycling van, recycling bins can contribute in creating awareness. However, the public must have complete information on the location of the bins and complete knowledge on the usage before expecting them to utilize recycling bins. The location of the recycling bins are important to encourage the public to recycle. Only those who are aware of the location of these bins can utilize it. There have been complaints as well about bins being stolen. As Silverboxes are made of steel a few had been stolen as well. Therefore, every municipality is provided with only a limited number to be placed at pedestrian walks.

With these evaluation, it is possible to answer the questions raised earlier. The results from ranking based only multicriteria suggests that public can be encouraged to practice recycling by providing more recycling vans at more frequent use and by providing them on more information on the location of bins. For example, the Subang Jaya City Council has a website that also updates the residents on recycling.

5 Concluding Remarks

We have proposed a slightly different eigenvector procedure in the context of PROMETHEE using the weighted sum of preference in-flow and out-flow to deal with outranking relation with discordance. Advantages of it are that the eigenvector is easy to understand and to calculate and that it is relatively robust in the change of components in the valued outranking relation. We demonstrated its application on the evaluation of recycling strategies in Malaysia.

To achieve the recycling objective, creating awareness and providing the necessary facilities have to be done simultaneously. From one of the surveys done by the Ministry of Housing and Local Authority in the year 2003, there is awareness among the public but not many are applying it.

In our analysis, the decision maker is the city council/ local authority. From the modified PROMETHEE analysis, the most effective way to create awareness among the public is by having exhibitions, carnival, briefing and through printed matters. People generally like carnivals. During exhibitions, the public can see hands-on some benefits from recycling. The most effective way of encouraging the public to recycle is by collecting the waste from house to house. Compared to recycling bins and recycling centers, recycling van is a new strategy and has proved to be more successful in luring the public to recycle. People seem more comfortable with recycling vans as they can utilize it simply by making a call. Many are not aware the location of recycling centers and some are too lazy to make the trip themselves.

As a first step in achieving the recycling objective, we have done an evaluation on how to create awareness among public and on how to increase the infrastructure to encourage the public to recycle. We hope this evaluation will provide some insight to the local authorities on how to tackle the lack of interest in recycling among the public. However, we would like to emphasize here that what we have proposed here is a preliminary step towards achieving the objective by the year 2020.

There are many stakeholders with different interest in recycling and have to be taken into consideration. Ranking of alternatives depend on the stakeholders and their objectives. As the stakeholders vary, the emphasis on the objectives also varies and this will result in the difference of ranking in alternatives. This matter will be elaborated in detail in our further research. In addition, our research will look at recycling in Subang Jaya and its successfulness.

Appendix

Proof of Theorem:

From (1), we have for any $\boldsymbol{a}_i$, $\boldsymbol{a}_j$,

$$\lambda_{max}\left(\psi^+(\boldsymbol{a}_i) - \psi^+(\boldsymbol{a}_j)\right) = \sum_{k=1}^{n} \left(\pi(\boldsymbol{a}_i, \boldsymbol{a}_k) - \pi(\boldsymbol{a}_j, \boldsymbol{a}_k)\right) \psi^+(\boldsymbol{a}_k) \tag{5}$$

Note that, either (i) $\boldsymbol{a}_i P \boldsymbol{a}_j$ or (ii) $\boldsymbol{a}_j P \boldsymbol{a}_i$ or (iii) $\boldsymbol{a}_i I \boldsymbol{a}_j$ exclusively holds.

We shall prove, if $\boldsymbol{a}_i P \boldsymbol{a}_j$, then $\psi^+(\boldsymbol{a}_i) > \psi^+(\boldsymbol{a}_j)$.

Since $\boldsymbol{a}_i P \boldsymbol{a}_j$ implies not $[\boldsymbol{a}_j P \boldsymbol{a}_i]$ by asymmetry of P, we get

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_j) = 1 \text{ and } \pi(\boldsymbol{a}_j, \boldsymbol{a}_i) = \varepsilon \tag{6}$$

It follows from the reflexivity of I that

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_i) = 1 \text{ and } \pi(\boldsymbol{a}_j, \boldsymbol{a}_j) = 1. \tag{7}$$

From (6) and (7), we have

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_j) = \pi(\boldsymbol{a}_j, \boldsymbol{a}_j), \tag{8}$$

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_i) > \pi(\boldsymbol{a}_j, \boldsymbol{a}_i). \tag{9}$$

For any $\boldsymbol{a}_k (k \neq i, j; k = 1, 2, \ldots, n)$, we have either $\boldsymbol{a}_j P \boldsymbol{a}_k$ or $\boldsymbol{a}_k P \boldsymbol{a}_j$ or $\boldsymbol{a}_j I \boldsymbol{a}_k$ exclusively.

(a) If $\boldsymbol{a}_j P \boldsymbol{a}_k$, then $\boldsymbol{a}_i P \boldsymbol{a}_k$ as P is transitive. That is,

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_k) = \pi(\boldsymbol{a}_j, \boldsymbol{a}_k) = 1. \tag{10}$$

(b) If $\boldsymbol{a}_k P \boldsymbol{a}_j$, which implies not $[\boldsymbol{a}_j P \boldsymbol{a}_k]$, then

$$\pi(\boldsymbol{a}_j, \boldsymbol{a}_k) = \varepsilon. \tag{11}$$

Since $\pi(\boldsymbol{a}_i, \boldsymbol{a}_k) \geq \varepsilon$, we have from (11)

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_k) \geq \pi(\boldsymbol{a}_j, \boldsymbol{a}_k) = \varepsilon. \tag{12}$$

(c) If $\boldsymbol{a}_j I \boldsymbol{a}_k$, then $\boldsymbol{a}_i P \boldsymbol{a}_k$. Thus, we have

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_k) = \pi(\boldsymbol{a}_j, \boldsymbol{a}_k) = 1. \tag{13}$$

From (8), (9), (10), (12) and (13), we have

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_k) \geq \pi(\boldsymbol{a}_j, \boldsymbol{a}_k), \qquad k = 1, 2, \ldots, n,$$

and

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_i) > \pi(\boldsymbol{a}_j, \boldsymbol{a}_i).$$

Since, from the well-known Perron's theorem (Saaty, 1990) , for a positive matrix, $\lambda_{max} > 0$ and $\psi^+(\boldsymbol{a}_k) > 0$, $k = 1, 2, \ldots, n$, it follows from (5) that

$$\psi^+(\boldsymbol{a}_i) > \psi^+(\boldsymbol{a}_j).$$

Thus, it is shown that

$$\text{if } \boldsymbol{a}_i P \boldsymbol{a}_j, \text{ then } \psi^+(\boldsymbol{a}_i) > \psi^+(\boldsymbol{a}_j) \tag{14}$$

Similarly, we have

$$\text{if } \boldsymbol{a}_j P \boldsymbol{a}_i, \text{ then } \psi^+(\boldsymbol{a}_j) > \psi^+(\boldsymbol{a}_i) \tag{15}$$

Finally, let us assume (iii) $\boldsymbol{a}_i I \boldsymbol{a}_j$. It follows that

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_j) = \pi(\boldsymbol{a}_j, \boldsymbol{a}_j) = 1, \tag{16}$$

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_i) = \pi(\boldsymbol{a}_j, \boldsymbol{a}_i) = 1. \tag{17}$$

For any $\boldsymbol{a}_k$, $(k \neq i, j; k = 1, 2, \ldots, n)$, we have either $\boldsymbol{a}_j P \boldsymbol{a}_k$ or $\boldsymbol{a}_k P \boldsymbol{a}_j$ or $\boldsymbol{a}_j I \boldsymbol{a}_k$ exclusively.

(a) If $\boldsymbol{a}_j P \boldsymbol{a}_k$, then $\boldsymbol{a}_i P \boldsymbol{a}_k$. Therefore,

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_k) = \pi(\boldsymbol{a}_j, \boldsymbol{a}_k) = 1. \tag{18}$$

(b) If $\boldsymbol{a}_k P \boldsymbol{a}_j$, then $\boldsymbol{a}_k P \boldsymbol{a}_i$. Thus

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_k) = \pi(\boldsymbol{a}_j, \boldsymbol{a}_k) = \varepsilon. \tag{19}$$

(c) If $\boldsymbol{a}_j I \boldsymbol{a}_k$, then $\boldsymbol{a}_i I \boldsymbol{a}_k$. Thus we have

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_k) = \pi(\boldsymbol{a}_j, \boldsymbol{a}_k) = 1. \tag{20}$$

From (16), (17), (18), (19), and (20)we have

$$\pi(\boldsymbol{a}_i, \boldsymbol{a}_k) = \pi(\boldsymbol{a}_j, \boldsymbol{a}_k), \qquad k = 1, 2, \ldots, n.$$

It follows from (5) that

$$\text{if } \boldsymbol{a}_i I \boldsymbol{a}_j, \text{ then } \psi^+(\boldsymbol{a}_i) = \psi^+(\boldsymbol{a}_j). \tag{21}$$

Since, for any $\boldsymbol{a}_i, \boldsymbol{a}_j$, only one of the following cases: $\boldsymbol{a}_i P \boldsymbol{a}_j, \boldsymbol{a}_j P \boldsymbol{a}_i, \boldsymbol{a}_i I \boldsymbol{a}_j$ occurs, it follows from (14), (15), and (21) that

$$\begin{aligned}
\boldsymbol{a}_i P \boldsymbol{a}_j &\quad \text{if and only if } \psi^+(\boldsymbol{a}_i) > \psi^+(\boldsymbol{a}_j), \\
\boldsymbol{a}_j P \boldsymbol{a}_i &\quad \text{if and only if } \psi^+(\boldsymbol{a}_i) < \psi^+(\boldsymbol{a}_j), \\
\boldsymbol{a}_i I \boldsymbol{a}_j &\quad \text{if and only if } \psi^+(\boldsymbol{a}_i) = \psi^+(\boldsymbol{a}_j).
\end{aligned}$$

In a similarly way, we have

$$\begin{aligned}
\boldsymbol{a}_i P \boldsymbol{a}_j &\quad \text{if and only if } \psi^-(\boldsymbol{a}_i) < \psi^-(\boldsymbol{a}_j), \\
\boldsymbol{a}_j P \boldsymbol{a}_i &\quad \text{if and only if } \psi^-(\boldsymbol{a}_i) > \psi^-(\boldsymbol{a}_j), \\
\boldsymbol{a}_i I \boldsymbol{a}_j &\quad \text{if and only if } \psi^-(\boldsymbol{a}_i) = \psi^-(\boldsymbol{a}_j).
\end{aligned}$$

which ends the proof.

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