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APPLICATION OF PROMETHEE METHOD FOR DEMAND SIDE MANAGEMENT (DSM) OPTIONS RANKING

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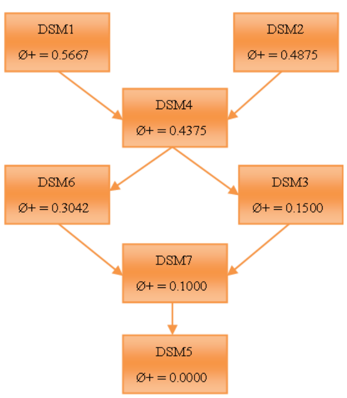
Graphical abstract



Abstract

Demand Side Management (DSM) is a method used to modify the electrical load profile of a consumer to reduce its electricity bill. There are various types of DSM options available but mostly involve costs to be incurred by consumers. Moreover, the effectiveness of a DSM option depends on various factors including investment cost, saved energy, payback period and more. Multi Criteria Decision Analysis (MCDA) is a tool that can be applied to make decision when a lot of factors to be taken into account. In DSM, Analytical Hierarchy Process (AHP) is one MCDA technique that is widely used in ranking the DSM options. However, AHP requires additive aggregation that may cause lost in detailed information. This paper presents another MDCA method; Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) to perform the ranking of DSM options. PROMETHEE (I and II) were used in a case study and the results shows that PROMETHEE give the same result as AHP. PROMETHEE has an advantage over AHP as it does not require additive aggregation even the problem is multi-dimensional and could provide visual analysis.

Keywords: Demand side management; multi criteria decision analysis,; analytical hierarchy process; preference ranking organization method for enrichment evaluation

1.0 INTRODUCTION

In our daily lives, electricity is one of the main sources to provide power to residential, commercial and industrial sector to allow economic development as to increase customer satisfaction. However, there is limitation to provide electricity because during peak period, many appliances are heavily used. The probability of overload increased and contributes to loss of electricity in specific duration. Since demand is fluctuating and unpredictable, an initiative from customer should be taken to control the electricity consumption during peak period. Even though customer behavior contribute to less energy reduction but it will result in a big reduction in new generating cost [1].

Demand Side Management (DSM) is an action that introduced by Gellings [2] to influence consumer for reducing energy usage besides altering and smoothing the load profile. Consequently, the concept of DSM was developed in response to the potential problems of global warming, the need for sustainable development and also the recognition that improved energy efficiency represents the most cost effective option to reduce the impacts of these problems. This will lead to the sustainability of electric grid that can avoid from blackout and carbon emissions. In addition, DSM is one of the significant efforts that lead to energy saving [3-5]. Electrical utilities has been continuously putting effort on running DSM programs to maximize the benefits for all the participants that involved in the energy management. These benefits include improving operation efficiency as improving the generation, transmission and distribution network by managing, balancing and closing the gap between demand and supply [5,6]. Furthermore, DSM counters the disadvantages of increasing of generation margin and need of transmission and distribution infrastructure upgrades [1].

A variety of DSM options are available for users but selection of the most appropriate DSM measure is perhaps a crucial question for the consumer. The best initiative is to know how does one evaluate all of the possibilities to determine which is the best DSM option. The main issue in this problem is to select best DSM options that are effective in energy saving as well as perceived short payback period. For selecting the best option, there are many approaches and methods that have been applied to rank and analyze the DSM options. For instance, multi objective optimization, priority index, cost benefit analysis and economic assessment. Special attention is given to the methodologies using Multi Criteria Decision Analysis (MDCA) method.

In this paper, Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) is applied for ranking DSM options in the context of decision making problem meanwhile Analytic Hierarchy Process (AHP) is used to attribute weights to the criteria since there is no specific guideline for PROMETHEE to weighting the criteria. This paper employed PROMETHEE, which is absent in the DSM options selection literature but is well known in other research areas.

2.0 MULTI CRITERIA DECISION ANALYSIS METHOD

Multi Criteria Decision Analysis (MCDA) is described as decision aid to evaluate the best choices among multiple criteria [7-9]. MCDA consist of structuring the problem in matrix form that usually considers the decision maker's preference. For instance, weighting the criteria need a comparison in which how criteria are important to other criteria based on decision maker's opinion. Weighted Sum Method (WSM) is considered as one of the simplest MCDA that eligible for evaluating the score of each alternative which determined by multiplying value of criteria with the value of alternatives itself. The limitation of WSM is set of criteria should be either benefit (positive) or cost (negative). However, the difficulty in MCDA occurred when there are different objectives criteria that consist of positive and negative criteria.

2.1 Analytical Hierarchy Process (AHP)

AHP is one of the MCDA method that been introduced by Saaty in the 1970s [10]. This method used pairwise comparison on ratio scale to weight the criteria. AHP is synthesized to compare both qualitative and quantitative criteria using expert opinion to determine relative weight of all criteria using 1-9 scale. This method has ability to decompose complex system into hierarchal structure in terms of alternatives, criteria and sub-criteria. In AHP, one criteria is compared with another criteria at one time based from decision maker and it is determined whether the criteria is extremely important, very strongly important, strongly important, moderately important or equally important with another criteria. Reciprocal is defined as multiplicative inverse and every number has a reciprocal value except 0. In AHP, reciprocal must be assigned in each of pairwise comparison matrix as shown below in matrix A. The terms of 'i' and 'j' represent the rows and columns of the matrix and 'a' represents the relative importance for each criteria.

$$\text{Matrix A} = \begin{bmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & 1 \end{bmatrix}$$

where $a_{ji=1}/_{a_{ij}}$ i, j = 1,........, n

2.2 Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)

PROMETHEE is another MDCA method developed by Brans and further extended by Vincke and Brans that has been used in different kind of decision making problems [11] such as water management, financial management, chemistry, social and others. It is also known as outranking method that compares options with other options to determine preference index. Two options are compared according to their preference degree.

In addition, finite options can be rank by considering multiple and conflicting criteria. PROMETHEE I is a partial ranking can be obtained by comparing the outgoing flow, $\emptyset^+$ and incoming flow, $\emptyset^-$. The best options should have greater outgoing flow while having smaller incoming flow. Two options for example, *a* and*b* are incomparable if outgoing flow and incoming flow for *a* bigger than *b* and also outgoing flow and incoming flow for *a* smaller than *b*. Let define the two total preorders (P^+ , I^+) and (P^- , I^-) such that:

$$\begin{cases} aP^+b & if\ \emptyset^+(a) > \emptyset^+(b) \\ aP^-b & if\ \emptyset^-(a) < \emptyset^-(b) \end{cases}$$

$$\begin{cases} aI^+b & if\ \emptyset^+(a) = \emptyset^+(b) \\ aI^-b & if\ \emptyset^-(a) = \emptyset^-(b) \end{cases}$$

PROMETHEE II need to be taken into account since it provides complete ranking which options is ranked according to their net flow, Ø which is the difference between outgoing and incoming flow. The steps to apply PROMETHEE method is given as follows:

Step 1: Build the decision making problem in matrix form:

$$\begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \vdots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix}$$

Step 2: Define the Preference function:

- Usual criterion
- Quasi-criterion
- Criterion with Linear Preference
- Level-criterion
- Criterion with Linear Preference and Indifference Area
- Gaussian criteria

Step 3: Calculate the Preference index:

$$d_j(a,b) = g_j(a) - g_j(b) \quad j=1,\ldots,k$$

$$P_j(a,b) = F_j[d_j(a,b)] \quad j=1,\ldots,k$$

$$\Pi(a,b) = \sum_{j=1}^{k} P_j(a,b) w_j$$

Step 4: Determine the value of outgoing flow and incoming flow:

$$\emptyset^+(a) = \frac{1}{n-1}\sum_{x\in A}\pi(a,x)$$

$$\emptyset^-(a) = \frac{1}{n-1}\sum_{x\in A}\pi(x,a)$$

Step 5: Calculate the total net flow and rank order:

$$\emptyset(a) = \emptyset^+(a) - \emptyset^-(a)$$

Based on the step shown above, $d_j(a,b)$ is the difference between the evaluation alternatives *a* and *b* within each criterion. $P_j(a,b)$ is defined as specified preference function after the evaluation between two alternatives at one time that ranges from 0 to 1. Π(a,b) is clarified as *a* is preferred to *b* within each criterion meanwhile Π(b,a) is interpreted as *b* is preferred to *a* according to each criterion. $\emptyset^+(a)$ that is outgoing flow indicated how much alternatives *a* is outranking other alternatives compared to $\emptyset^-(a)$ that is incoming flow is described as how much alternatives *a* is outranked by other alternatives. Ø(a) is a net flow that is deviation between these two flows to obtain final ranking,

3.0 DSM OPTIONS RANKING USING MCDA

Traditionally, no cost DSM options could be determined as one of the best options. However, this option could not be guaranteed as the best option since low or high cost DSM options usually reduce more energy [12]. Remarkably, different DSM options may have different impact on energy and peak reduction as well as customer acceptance which make the DSM selection very complex. Single criteria decision analysis is unavailable to handle with these kinds of problem because having more than one conflicting criteria. By using appropriate MCDA methods, all DSM options can be prioritized effectively regarding the criteria that affect the performance of building.

Blondeau et al [13] applied Elimination Choice Expressing Reality (ELECTRE) to determine best ventilation strategy in university building to increase indoor environment quality. Three criteria have been selected which are thermal comfort, indoor air quality and energy cost.

Caccavelli et al used TOBUS as a tool to choose most cost-effective options for office building upgrading. A set of retrofit actions could be referred in [14] and criteria that affect choices of decision analysis are user needs, flexibility, visibility, maintainability and compliance with regulations.

W Guo-hua et al [15] employed Analytic Network Process (ANP) for industrial enterprises to evaluate Energy Saving and Emission Reduction (ESER). Firstly, index system of ESER is developed by considering energy saving, pollutant reduction, multiple utilization, decontaminate, economically and management and case study in industrial sector is applied to test the reliability of ESER based on ANP.

4.0 CASE STUDY: APPLICATION OF PROMETHEE IN DSM OPTIONS RANKING

The case study is taken from a study in [16]. Seven DSM options have been proposed which consists of five technological options and two policy options. The list of DSM options is given in Table 1.

In this decision making context, the multiplicity of criteria is needed for the selection among different options. Six criteria is used in this case study which are; i) Saved Energy, ii) Peak Load Reduction, iii) Investment Cost, iv) Payback Period, v) Penetration Rate and vi) Technology Acceptance. The judgments from expert opinion and the pairwise comparison for the six criteria are stated in Table 2. It can be describes as for row no 1 which saved energy that is equally important with peak load reduction in column no 2. Same as investment cost in row no 3 that is equally important with payback period in column no 4.

Table 1 DSM options

No	DSM options
DSM1	Thermostat setting
DSM2	High efficiency lighting
DSM3	Efficient air conditioning equipment
DSM4	Roof and wall insulation
DSM5	Efficient end-use equipment
DSM6	Increase of electricity tariff
DSM7	Energy efficiency labels and standards

Table 2 Pairwise Comparison Matrix for the Six Criteria [16]

Criteria	Saved Energy	Peak Load Reduction	Investment Cost	Payback Period	Penetration Rate	Technology Acceptance
Saved Energy	9/9	9/9	9/7	9/7	9/5	9/3
Peak Load Reduction	9/9	9/9	9/7	9/7	9/5	9/3
Investment Cost	7/9	7/9	7/7	7/7	7/5	7/3
Payback Period	7/9	7/9	7/7	7/7	7/5	7/3
Penetration Rate	5/9	5/9	5/7	5/7	5/5	5/3
Technology Acceptance	3/9	3/9	3/7	3/7	3/5	3/3
SUM	40/9	40/9	40/7	40/7	40/5	40/3

Table 3 Synthesized Matrix for the Six Criteria [16]

Criteria	Saved Energy	Peak Load Reduction	Investment Cost	Payback Period	Penetration Rate	Technology Acceptance	**Priority Vector**
Saved Energy	0.225	0.225	0.225	0.225	0.225	0.225	**0.225**
Peak Load Reduction	0.225	0.225	0.225	0.225	0.225	0.225	**0.225**
Investment Cost	0.175	0.175	0.175	0.175	0.175	0.175	**0.175**
Payback Period	0.175	0.175	0.175	0.175	0.175	0.175	**0.175**
Penetration Rate	0.125	0.125	0.125	0.125	0.125	0.125	**0.125**
Technology Acceptance	0.075	0.075	0.075	0.075	0.075	0.075	**0.075**
SUM	1.000	1.000	1.000	1.000	1.000	1.000	**1.000**

Final priority vector for six DSM criteria is shown in Table 3. It could be explained that saved energy and peak load reduction is the most important DSM criteria meanwhile technology acceptance is less important DSM criteria. Table 4 showed the proposed scores of identified DSM options. The description and explanation of each DSM options can be referred in [16]. Meanwhile, Table 5 indicated the preference parameters for all six DSM criteria. W_i, q_i and p_i are refer to weight, indifference threshold and preference threshold for each criteria. For rating scale assessment like expert opinion, the PROMETHEE guidelines advise to apply a linear preference function.

After implementing PROMETHEE I (partial ranking) and the outgoing flow and the incoming flow, it clearly shows that DSM1 and DSM2 is incomparable and same goes to DSM3 and DSM6. It is because the incoming flow for DSM1 is bigger than DSM2 and the incoming flow for DSM6 is bigger than DSM3. The result from PROMETHEE I and the visual computation of the total net flow are shown in Table 6 and Figure 1 respectively.

From Table 6, PROMETHEE II which is complete ranking can be determined by sorting the total net flow, Ø in decreasing order. By comparing the result with previous research work that used AHP method for ranking DSM options, it has the same ranking options which are DSM1 is the best option followed by DSM2, DSM4, DSM6, DSM3, DSM7 and DSM5. The final ranking is shown in Table 7. A clearly comparison shown in Table 7 as AHP and PROMETHEE method provide same ranking results.

Table 4 Proposed scores of seven DSM options [16]

DSM Option	Saved Energy	Peak Load Reduction	Investment Cost	Payback Period	Penetration Rate	Technology Acceptance
DSM1	3	3	9	9	5	7
DSM2	5	3	5	7	5	5
DSM3	3	3	5	5	1	3
DSM4	5	5	5	5	1	5
DSM5	1	1	5	3	1	3
DSM6	3	1	9	7	3	1
DSM7	3	1	5	3	3	1

Table 5 Proposed preference parameters of all six criteria

Criterion	Function	w_i	q_i	p_i
Saved Energy	Linear	0.225	0	2
Peak Load Reduction	Linear	0.225	0	2
Investment Cost	Linear	0.175	0	2
Payback Period	Linear	0.175	2	4
Penetration Rate	Linear	0.125	0	2
Technology Acceptance	Linear	0.075	2	4

Table 6 Computation of total net flow for all DSM options

DSM options	$\emptyset^+$	$\emptyset^-$	$\emptyset$
DSM1	0.5667	0.1125	0.4542
DSM2	0.4875	0.0958	0.3917
DSM3	0.1500	0.2958	-0.1458
DSM4	0.4375	0.1708	0.2667
DSM5	0.0000	0.6167	-0.6167
DSM6	0.3042	0.3042	0.0000
DSM7	0.1000	0.4500	-0.3500

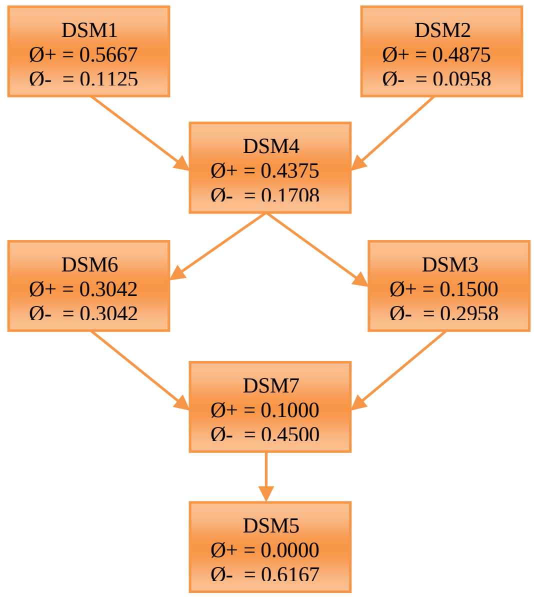


Figure 1 Visual computation of the total net flow using PROMETHEE I

Table 7 Complete ranking from PROMETHEE II

Ranking	DSM Options	Net Flow, Ø
1st	DSM1	0.4542
2nd	DSM2	0.3917
3rd	DSM4	0.2667
4th	DSM6	0.000
5th	DSM3	-0.1458
6th	DSM7	-0.3500
7th	DSM5	-0.6167

Table 8 Ranking comparison between PROMETHEE and AHP

Ranking	Using PROMETHEE method		Using AHP method [16]	
	Ø	DSM option	Ø	DSM option
1st	0.4542	DSM1	0.203	DSM1
2nd	0.3917	DSM2	0.193	DSM2
3rd	0.2667	DSM4	0.175	DSM4
4th	0.000	DSM6	0.136	DSM6
5th	-0.1458	DSM3	0.133	DSM3
6th	-0.3500	DSM7	0.087	DSM7
7th	-0.6167	DSM5	0.073	DSM5

5.0 CONCLUSION

In this paper, multi criteria decision analysis based on outranking method is provided for ranking DSM options. Different DSM options are applied for selecting best DSM options with given criteria. AHP is applied to determine criterion weights meanwhile PROMETHEE I and II are used in this paper to set priority for all DSM options. Since it has an option that is incomparable with other options, PROMETHEE I could not provide a complete ranking for selecting best DSM options. PROMETHEE II can provide the complete ranking by calculating the difference between total outgoing flow and total incoming flow. The comparison study shows that PROMETHEE II gives the same results as AHP. PROMETHEE has advantage over AHP in terms of simple ranking method, provide visual analysis result and does not require additive aggregation that may cause lost in detailed information. In ranking problem, AHP tend to have more pairwise comparison to be completed in terms of alternatives with respect to each criterion. However, AHP is a most widely applied in weighting the criteria because of its simplicity in use. The key motivation of this situation is an integrated between AHP and PROMETHEE that will combine in a single MCDA tool with AHP determining the weight and PROMETHEE providing final ranking since there is no specific guidelines for PROMETHEE to weight the criterion. Moreover, PROMETHEE avoids potential trade-off between best and worst one on criteria, which is likely to happen in complete aggregation methods in AHP for ranking.

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