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Plant location selection by using MCDM methods

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ABSTRACT
Plant location selection has a critical impact on the performance of manufacturing companies. The cost associated with acquiring the land and facility construction makes the location selection a long-term investment decision. The preeminent location is that which results in higher economic benefits through increased productivity and good distribution network. Both potential qualitative and quantitative criteria's are to be considered for selecting the proper plant location from a given set of alternatives. Consequently, from the literature survey, it is found that the Multi criteria decision-making (MCDM) is found to be an effective approach to solve the location selection problems. In the present research, an integrated decision-making methodology is designed which employs the two well-known decision making techniques, namely Analytical hierarchy process (AHP), and Preference ranking organization method for enrichment evaluations (PROMETHEE-II) in order to make the best use of information available, either implicitly or explicitly. It is analyze the structure for the solution of plant location problems and to obtain weights of the selected criteria's. PROMETHEE-II is employed to solve decision-making problems with multiple conflicting criteria and alternatives.
Keywords -Analytical Hierarchy Process (AHP), Location Selection, Multi Criteria Decision Making (MCDM), PROMETHEE II, weighted average
Abbreviations- C*-Cost; F*-Facility; T*-Transportation; L*-Labor***;*** P*-Priority vector; T.C*-Transportation cost; P-Priority.

I. INTRODUCTION

The plant location problem has significant impacts on the efficiency of manufacturing companies [1]. The decision maker must select the location for a facility that will not only perform well, but also it will be flexible enough to accommodate the necessary future changes. The success or failure of a financial organization mainly depends on the consideration of the criteria as they directly influence the institutional performance. Selection of a proper location involves consideration of multiple feasible alternatives. It is also observed that the selection procedure involves several objectives and it is often necessary to make compromise among the possible conflicting criteria [2]. For these reasons, Multi Criteria Decision-Making (MCDM) is used. MCDM approaches provide a systematic procedure to help decision makers to choose the most desirable and satisfactory alternative under uncertain situation. In this paper, Analytic Hierarchy Process (AHP) and the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE II) are employed to obtain the best choice from a finite set of alternative facility locations. While applying the AHP/PROMETHEE II method is employed to solve a real time facility location selection problem, it is observed that this method proves its applicability and potentiality to solve such type of decision-making problems with multiple conflicting criteria and alternatives.

II. LITERATURE REVIEW

Facility location is one of the popular research topics in decision-making activities. These problems have received much attention over the years and numerous approaches, both qualitative and quantitative [3] have been suggested. Generally, research in plant location area has been focused on optimizing methodology (Brown and Gibson, 1972; Erlenkotter, 1975; Rosenthal, White and Young, 1978; Wesolowsky, 1977). Extensive effort has been devoted to solving location problems employing a wide range of objective criterion and methodology used in the decision analysis. The PROMETHEE-I (partial ranking) and PROMETHEE-II (complete ranking) were developed by J.P. Brans and presented for the first time in 1982 at a conference organized by R. Nadeau and M. Landry at the University Laval, Québec, Canada (L'Ingéniérie de la Decision. Elaboration d'instrumentsd'Aideà la Decision). Randhawa and West [4] proposed a solution approach to facility location selection problems while integrating analytical and multi-criteria decision-making models. Houshyar and White [5] developed a mathematical model and heuristics approach that assigns N machines to N equal-sized locations on a given site such that the total adjacency flow between the machines is maximized. Owen and Daskin [6] provided an overview of the methodologies that have been developed for solving facility location selection problems.

Ⅲ. PROPOSED METHODOLOGIES

Analytic Hierarchy Process (AHP)

AHP, develop by Saaty [7] (1980), addresses how to determine the relative importance of a set of activities in a multi-criteria decision problem. It decomposes and simplifies the problem. It deals with tangible qualitative criteria alongside tangible quantitative criteria [8, 9].The AHP method is based on three principles: first, structure of the model; second, comparative judgment of the alternatives and the criteria; third, synthesis of the priorities.

Step1: Determination of criteria's, their sub criteria's and locations. Construct a hierarchal structure of the model.1

Step2: Determinations of relative importance of each of the alternative with respect each criterion and find the priority vector by using the formula

$$p = \frac{1}{n}\sum_{j=1}^{n}\frac{aij}{\sum_j^n aij} \qquad i,j = 1,2 \ldots. n \qquad \text{------- (1)}$$

n = number of criteria

Step3: overall priority weight determination of each of these alternatives and comparing the weight with the locations.

Step4: multiply each value in the first column of the pair-wise comparison matrix by the relative priority of the first item considered. Continue the same procedure for other items. Sum the values across the row to obtain a vector of values labeled "weighted sum factor" (wsf)

$$wsf = \sum aij * pj \qquad i,j = 1,2 \ldots \ldots n \text{ ------ (2)}$$

Step5: divide the elements of the vector weighted sum obtained in step4 by the corresponding priority values to get the consistency vector [10]

Consistency vector=wsf_i/p_i ---------------- (3)

Step6: compute the average of the values computed in step5. This average is denoted as λ_{max} [11, 12].

Step7: compute the consistency index (C.I)

$$C.I = (\lambda_{max} - n)/(n-1) \qquad \text{------------ (4)}$$

Where n is the number of items being comparing

Compute the consistency ratio (CR) = CI/RI.

Ⅳ. CASE STUDY

As a case study for location selection problem, four locations have been selected to choose the best one with required criteria's. They are Ultra-tech cement factory at Bogasamudra (L1), Bharathi cement factory at Kadapa (L2), Lanco cement factory at Srikalahasthi (L3) and Penna cement industries at Tadipatri (L4). The main factors considered in this problem are cost, facility, transportation and labor. Sub-factors considered in this case study are land cost (C1) in which plant is constructed, initial investment (C2), setup cost (C3), viability and cost of energy (C4) like gas, electricity etc., transportation cost (C5), availability of raw materials (C6), ease of expansion (C7), inbound transportation cost (C8) includes material handling cost, inventory maintenance cost etc., , outbound transportation cost (C9) includes imports and export of materials, availability of skilled labor (C10), labor force competitors (C11), employment rate (C12) and wage rate (C13). AHP hierarchy can be multi-level hierarchy. The Saaty scale is considered to compare the relative importance one over the other.

Table1: SAATY rating scale

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgment slightly favor one over the other
5	Much more important	Experience and judgment strongly favor one over the other
7	Very much more important	Experience and judgment strongly favor one over the other. Its importance is demonstrated in practice
9	Absolutely more important	The evidence favoring one over the other is of the highest possible validity
2,4,6,8	Intermediate values	When compromise is needed

Based on proposed methodology, the steps are applied for assessment and selection of plant location. In this part we deal with application of these steps.

Step1:

The first step of AHP is the hierarchal structure of the plant location selection.

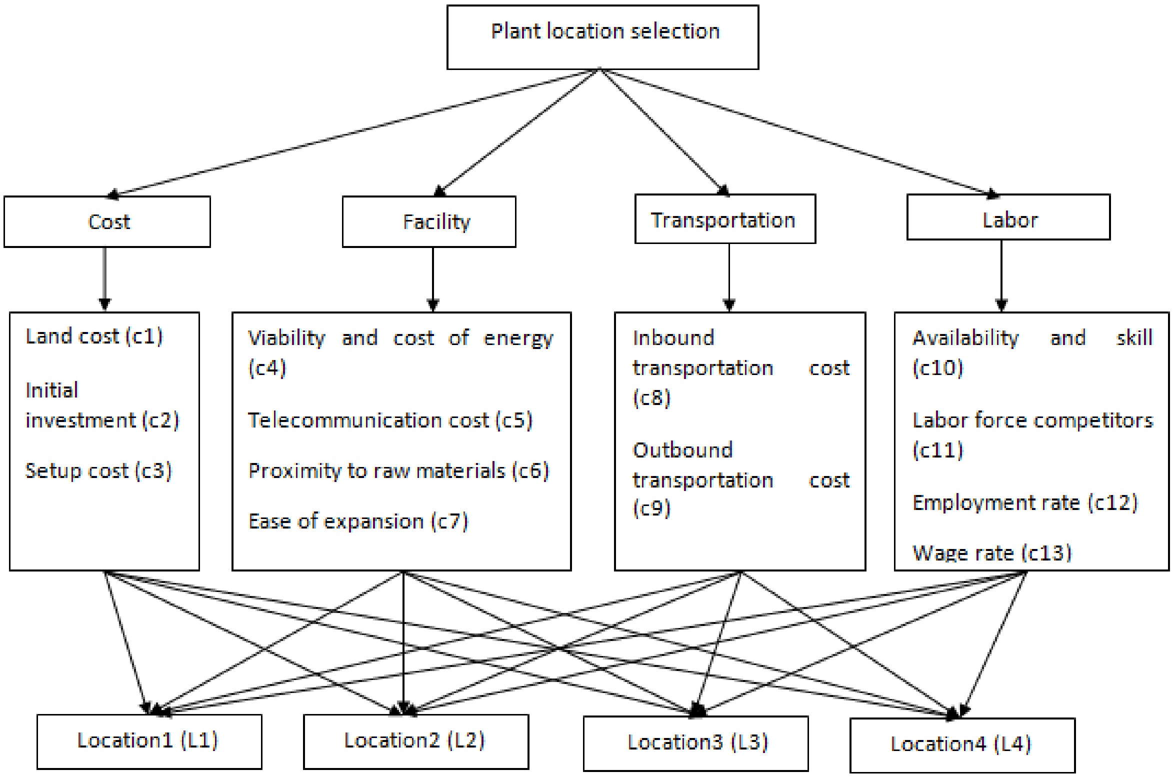

Fig1. Hierarchal structure of the AHP model.

Step2:
Table2: Comparison matrix for criteria

Criteria	C*	F*	T*	L*	P*
C*	1	7	2	3	0.462
F*	1/7	1	4	3	0.249
T*	1/2	1/4	1	5	0.209
L*	1/3	1/3	1/5	1	0.079

Table3: Comparison matrix for cost sub-criteria

C*	C1	C2	C3	P*
C1	1	1/5	1/7	0.0810
C2	5	1	6	0.6521
C3	7	1/6	1	0.6320

Table4: comparison matrix for facility sub-criteria

F*	C4	C5	C6	C7	P*
C4	1	1/5	1/4	1/4	0.0630
C5	5	1	5	7	0.5690
C6	4	1/5	1	1/5	0.1310
C7	4	1/4	5	1	0.2350

Table5: comparison matrix for transportation sub-criteria

T.C*	C8	C9	P*
C8	1	1/4	0.3
C9	4	1	0.8

Table6: comparison matrix for labor sub-criteria

L*	C10	C11	C12	C13	P*
C10	1	5	7	9	0.6340
C11	1/5	1	1/4	1/3	0.0668
C12	1/7	4	1	1/3	0.3510
C13	1/9	3	3	1	0.1660

Table7: Comparison matrix between C1 and locations

C1	L1	L2	L3	L4	P*
L1	1	1/2	1	3	0.2360
L2	2	1	3	2	0.4320
L3	1	1/3	1	2	0.1860
L4	1/3	1/2	1/2	1	0.1460

Table8: Comparison matrix between C2 and locations

C2	L1	L2	L3	L4	P*
L1	1	1/3	1	1/3	0.1340
L2	3	1	3	2	0.4570
L3	1	1/3	1	1	0.1710
L4	3	1/2	1	1	0.2390

Table9: **Comparison matrix between C3 and locations**

C3	L1	L2	L3	L4	P*
L1	1	1/4	1/3	1/5	0.8800
L2	4	1	1/3	1/2	0.1690
L3	3	3	1	1	0.3780
L4	5	2	1	1	0.3650

In the same way calculated comparison matrices between all the sub-criteria's and locations were summarised in the table shown below

Table10: **final priority table**

criteria	P	Sub-criteria	P	L1	L2	L3	L4
C*	0.46	C1	0.08	0.23	0.43	0.18	0.14
		C2	0.65	0.13	0.45	0.17	0.23
		C3	0.63	0.88	0.16	0.38	0.36
F*	0.25	C4	0.23	0.27	0.53	0.12	0.07
		C5	0.06	0.28	0.53	0.11	0.08
		C6	0.56	0.29	0.50	0.14	0.06
		C7	0.13	0.50	0.30	0.14	0.05
T*	0.21	C8	0.30	0.18	0.14	0.38	0.29
		C9	0.80	0.19	0.15	0.38	0.26
L*	0.08	C10	0.63	0.13	0.36	0.21	0.28
		C11	0.06	0.21	0.31	0.06	0.41
		C12	0.35	0.20	0.12	0.06	0.62
		C13	0.16	0.36	0.37	0.22	0.06
Total weight				0.30	0.34	0.19	0.23

Step4: Weighted sum factor

Table11: **Normalized matrix of Table-1**

	Normalized matrix				
criteria	C*	F*	T*	L*	P*
C*	0.5000	0.7912	0.2758	0.2727	0.4599
F*	0.0830	0.1318	0.5517	0.2727	0.2598
T*	0.2500	0.0329	0.1329	0.3636	0.1961
L*	0.1665	0.0439	0.0345	0.0909	0.0839

For C*: (0.5*0.4599) + (0.7912*0.2598) + (0.2758*1961) + (3*0.0839) = 2.6626

Weighted sum factor for other criteria`s can be calculated by using the equation (2).

Step5: Consistency vector

For C*: 2.6626/0.4599 = 5.7895

In the same way consistency vectors for remaining criteria`s can be calculated by using equation (3).

Step6: $\lambda_{max} = 4.1896$

Step7: Due to the difficult decision and the limited human discernment, several contradictions or meanderings may occur in connection to the listed demands. In order to detect such inconsistencies, SAATY developed:

a consistency ratio (C.R.) and

a consistency index (C.I.) [13, 14, 15].

$C.I = (\lambda_{max} - n)/(n-1) = (4.1896-4)/3 = 0.0632$

Check for consistency using consistency ratio (C.R) = C.I/R.I

Where R.I is Random Consistency Index

Table12: **RCI values for different values of *n***

n	1	2	3	4	5	6	7	8
R.I	0	0	0.58	0.9	1.12	1.24	1.32	0.41

The outcome for the consistency value, having a R.I of 0.9 for n = 4 is

C.R = 0.0632/0.9 = 0.07

If the CR value is greater than 0.10, then it is a good idea to study the problem further and re-evaluate the pair wise comparisons.

Table13: **priority order**

	Weight	rank
L1	30%	2
L2	34%	1
L3	19%	4
L4	22%	3

The high total weight of the location (L2) shows that it is the best location out of all considered locations due to moderate land cost, low setup cost, high initial investment. The availability of energies like electricity and gas is even more, lesser telecommunication cost, higher availability of raw materials, more chances to ease of expansion. The location has more availability of skilled workers, moderate wage rate and employment rate.

V. PROMETHEE II methodology:

Preference function based outranking method is a special type of MCDM tool that can provide a ranking ordering of the decision options. The PROMETHEE (preference ranking organization method for enrichment evaluation) method was developed by Brans and Vincke in 1985 [16]. The PROMETHEE I method can provide the partial ordering of the decision alternatives, whereas, PROMETHEE II method can derive the full ranking of the alternatives. The procedural steps as involved in PROMETHEE II method are enlisted as below [17, 18]

STEP 1: Normalize the decision matrix using the following equation:

$R_{ij} = [X_{ij} - \min (X_{ij})] / [\max (X_{ij}) - \min (X_{ij})]$ (i=1, 2, 3……, j=1, 2….m) (5)

Where,

X_{ij} is the performance measure of i^{th} alternative with respect to j^{th} criteria.

STEP 2: Calculate the evaluative difference of i^{th} alternative with respect to other alternative. This step involves the calculation of differences in criteria values between different alternative pair wise.

STEP 3: Calculate preference function, P_j (i, i')

P_j (i, i') =0 if $R_{ij} <= R_{i`j}$

P_j (i, i') = ($R_{ij} - R_{i`j}$) if $R_{ij} > R_{i`j}$

STEP 4: The aggregate preference function taking in to account the criteria weight.

Aggregate preference function,

$$\prod_{j=1,j=1}^{m,m} = \frac{\sum W_j P_j(i,j)}{\sum W_j} \quad \text{---------------------------- (6)}$$

Where W_j is the relative importance (weight) of j^{th} criteria

STEP 5: Determine the leaving and entering outranking flows as follows:

Leaving or positive flow for i^{th} alternative

$$\Phi^{+}(i) = \frac{1}{n-1}\sum_{i`=1}^{n} \pi(i, i`) \quad \text{for } (i \neq i') \text{ ---- (7)}$$

Entering or negative flow for i^{th} alternative

$$\Phi^{-}(i`) = \frac{1}{n-1}\sum_{i`=1}^{n} \pi(i, i`) \quad \text{for } (i \neq i') \text{ ---- (8)}$$

Where, n is the number of alternatives.

Here, each alternative faces (n-1) other alternatives. The leaving flow express how much an alternative dominates the other alternative, while the entering flow denotes how much an alternative's dominated by other alternatives. Based on these outranking flows, the PROMETHEE-1 method provide a partial pre order of the alternatives, whereas the PROMETHEE-2 method give the complete pre order by using the net flow, though it losses much information of preference relations.

Calculate the net outranking flow for each alternative.

$\Phi(i) = \Phi^{+}(i) - \Phi^{-}(i)$ ------------------------- (9)

Determine the ranking of all the considered alternatives depending on the values of ϕ (i). The higher value of ϕ (i), the better is alternative. Thus the best alternative is the one having the highest ϕ (i) value.

VI. CASE STUDY

The same example is considered here to demonstrate the applicability and effectiveness of PROMETHEE II method as a MCDM tool. This example takes into account thirteen facility location selection criteria and four alternative facility locations. The objective and sub-objective information regarding different location selection criteria are taken from the AHP' methods are shown in the below table. Based on proposed methodology, the steps are applied for assessment and selection of plant location.

Table14: Selecting criteria for location selection and Weight

code	Criteria	weight
C1	Land cost	0.081
C2	Initial investment	0.6521
C3	Setup cost	0.632
C4	Viability and cost of energy	0.235
C5	Telecommunication cost	0.063
C6	Proximity to raw materials	0.569
C7	Ease of expansion	0.131
C8	Inbound transportation cost	0.3
C9	Outbound transportation cost	0.8
C10	Availability and skilled labor	0.634
C11	Labor force	0.0622
C12	Employment rate	0.351
C13	Wage rate	0.166

Step1:

Table15: Normalized decision matrix

locations	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
L1	0	0	1	0.3287	0.5479	0.5479	1	0.4363	0	0	0	0	0.4363
L2	1	1	0	1	1	1	0.5479	0	0	1	0.7741	0.2637	1
L3	0	1	0.2739	0	0	0	0	1	1	0	0	0	0.4363
L4	0	0.5753	0.3767	0	0	0	0	0.7272	0.5945	0.5479	1	1	0

Step3:
Table 16: Preference functions for all the pairs of alternative

Location pairs	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
(L1,L2)	1	1	0	0.67	0.45	0.45	0	0	0	1	0.77	0.2	0.56
(L1,L3)	0	1	0	0	0	0	0	0.56	1	0	0	0	0
(L1,L4)	0	0.57	0	0	0	0	0	0.29	0.59	0.54	1	1	0
(L2,L1)	0	0	1	0	0	0	0.45	0	0	0	0	0	0
(L2,L3)	0	0	0	0	0	0	0	1	1	0	0.22	0	0
(L2,L4)	0	0	0	0	0	0	0	0.72	0.59	0	0	0.73	0
(L3,L1)	0	0	0.72	0.3	0.54	0.54	1	0	0	0	0.77	0	0
(L3,L2)	1	0	0	1	1	1	0.59	0	0	0.54	1	0.26	0.56
(L3,L4)	0	0	0.1	0	0	0	0	0	0	0	0	1	0
(L4,L1)	0	0	0.62	0.5	0.54	0.54	1	0	0	0	0	0	0.43
(L4,L2)	1	0	0	1	1	1	0.5	0	0	0.45	0	0	1
(L4,L3)	0	0.4247	0	0	0	0	0	0.27	0.40	0	0	0	0.43

Step4:
Table17: Aggregate preference function

locations	L1	L2	L3	L4
L1	-	0.9981	0.9252	0.9481
L2	0.99	-	1.035	0.9614
L3	0.87	0.917	-	0.7916
L4	0.08	1.0946	0.0502	-

Step5:
Table18: Leaving and entering flows for different supplier

locations	Entering flow	Leaving flow
L1	0.9538	0.6528
L2	1.3366	0.9999
L3	0.8432	0.6456
L4	0.780	0.55332

Table19: Net Outranking Flow values for different supplier

Locations	Net out Ranking Flow	Rank
L1	0.301	2
L2	0.3332	1
L3	0.1936	4
L4	0.2201	3

VII. RESULT AND ANALYSIS

The location with the highest net out ranking flow is considered as the best location with required inputs. The results are same as the AHP`s methodology with precision. By applying this methodology, best result is obtained without any errors.

VIII. CONCLUSION

Location selection decision has long-term implications because changing the locations of the existing facilities may be quite expensive. It is therefore important to select the most appropriate location for a given industrial application which will minimize the cost over an extended time period. The problem of facility location selection is a strategic issue and has significant impact on the performance of the manufacturing organizations. The present study explores the use of AHP and PROMETHEE II method in solving a location selection problem and the results obtained can be valuable to the decision maker in framing the location selection strategies. It is also observed that this MCDM approach is a viable tool in solving the location selection decision problems. It allows the decision maker to rank the candidate alternatives more efficiently and easily. The cited real time industrial example demonstrates the computational process of the AHP and PROMETHEE II method and the same can also be applied to other strategic decision-making problems.

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