SELECTING FACILITY LOCATION USING HYBRID METHODOLOGIES IN GLOBAL PERSPECTIVE: A CASE OF CEMENT PLANT

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ABSTRACT

While selecting a global facility location, the decision makers normally have to face two types of scenarios: exploring and prioritizing the factors affecting the location decision and selecting an appropriate optimization methodology,-compatible to the said problem.This paper addresses a real world case study of the problem of selecting a country best suitable for a new cement plant installation among the list of four alternatives. The irreversible nature of the crucial decision requires analysis of wide range of factors with different optimization techniques.Therefore such factors were explored and prioritized from available literature and by recommendations of panel of experts followed by mathematical modelling of the said problem in four standard methodologiesincluding the one presented in another paper earlier.Thesolutionswere obtained by coding routines in theconcerned programs.Stability analysis with respect to change of priorities and change of cost and capacity constraints has provided an in depth scenario evaluation which has added value to the degree of reliability and confidence regarding acceptability of results. The paper is a unique contribution for strategic managers of the cement sector being an aid tomake confident global decisions.

KEYWORDS: *Global Facility Location; Multi Criteria Decision Making(MCDM); Optimization;Process Industry*

INTRODUCTION

Leading firms of the world are striving to capture the global markets in this era of globalization. Global businesses often move their facilities across the borders as the products can be manufactured more cheaply indifferent countries due to lower production costs. However, many factors other than the production costssignificantly influence a global business. It is therefore necessary to explore all such influencing factors andthen chosethose which are critical from global perspective.Once these factors are identified, it is followed by searching the specific country for global manufacturing site. Methodologies used in this paper are different approaches under the umbrella of Multi-criteria Decision Making(MCDM). The critical problem demands reliable results which may not be possible by a single methodology. Therefore it has been solved by four different methodologies with multiple scenarios.Analytical Hierarchy Process (AHP) model was developed and solved in the first phase[1]. The current paper is a continuation of that research work. Results of AHP model are used as one of the goals in Goal Programming (GP) modelling and the AHP model is again utilized for the sensitivity/stability analysis.

LITERATURE REVIEW

For years, researchers from industry and academia had been focussing on facility location methodologies and their real world applications. A variety ofmodels mostly based on mathematical programming focusing the goals like maximization of profits and minimization of costs have beendeveloped and applied.However, surprisingly, very less research work is found addressing the problem of locating a new cement production facility in different countries of the world.

Since the problem depends on a wide range of influencing factors, it is an area justified for the application of MCDM models.Therefore most of the tools used in available literature for global facility location are the MCDM tools.Farahani et al[2]. have compiled a review on the facility location problem in three categories including bi-objective, multi-objective and multi-attribute. They have suggested researchers to increase the range of influencing factors from cost based factors to environmental and ethical issues and from deterministic approaches to stochastic ones.

Ataei[3], used AHP for new alumina-cement plant location in East Azerbaijan province of Iran. The research is based on five critical affecting factors with transportation cost being taken as the most important one.

The process industry such as textiles and apparel was studied for selecting best location in global context[4].

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The methodologies evaluated and applied include scaling, scoring, ranking methods, analytic hierarchy process (AHP) methodology, mathematical programming methods, heuristic algorithms and simulation methods.

A lot of research had been found in literature addressing the facility location science within the national borders as presented in the bibliography compiled by Re Velle et al[5]. which is an excellent source of knowledge on algorithms and methodologies applied for the said problem at national level. However the reader can visualize a clear research gap on the issue of site locations for global enterprises of future.

There are many applications of AHP and mathematical programming in facility location problems. In first phase of thecurrent paper, authors have applied the AHP alone model to solve the same problem with same data[1]. The results are used as one input of GP model. Sauian[6] used AHP approach to select plant locationand concluded that the methodology is an advantageous approachfor multi-criteria facility location problems.

The integrated use of Analytical Hierarchal Process (AHP) combined with other methodologies like GPhaveflourished recently. Badri[7] suggested AHP-GP approach to evaluate six possible locations for a petrochemical company in the Middle East. The AHP weighting is combined in a GP model that includes resource limitations in the location-allocation decision process.Another hybrid approach is presented by Canbolt et al[8]. The approach consists of different phases for selecting a country to locate a global manufacturing facility. Authors have combined the multi attribute utility theory (MAUT) with an influence diagram. It is afocused research incorporating a variety of measures for which national data were readily available.

Ada et al[9]. also developed and applied hybrid linear integer programming-AHP modelsfor the location selection problems.The methodology developed was combination of both qualitative and quantitative factors. Initially the factors were stated;then the quantitative factors were modelled based on the cost figures. An inversely normalized order was assigned to each factor used in the linear integer programming model and the qualitative factors were subject to AHP.

Apart from the stand alone, hybrid and combined approaches, some researchers used subjective questionnaire.Using decision factor analysis and the analytic hierarchy process a model was proposed which include a criterion set having twenty criteria divided intofive groups. A questionnaire developed was filled by 180 managers in the distribution arena. This research strongly supported the integrated tool developed for distribution facilities using subjective judgement[10].

The structured approach was proposed by Canel and Das[11] using simulation and AHP in an integrated way. The proposed manufacturing utility is related to marketing utility through facility location decisions. Mathematical model for global facility location integratedwithin marketing and manufacturing decisions in global contextwas developed

Yang and Lee[12] used a comprehensive set of affecting factors while evaluating three potential sites by taking into account the factors from major categories of objectives including market, transportation, labour, and community. The work of Canel and Das[11] is also significant in which focus was formulations of both capacitated and un-capacitated multiperiod international facility location problems. The authors applied GP models for global site location problem. A case study based on a two-phase process for the selection of a facility site in Europe for a US brewery expansion was focussed by Hoffman and Schnieder jans[13]. Japanese manufacturers examined many global location factors for the decision ofglobal plant location including labour, markets, transportation, financial inducement and living conditions. To evaluate the countries and then the sites within the selected countries,an AHP model was presented[14]

Global site location decisions cannot be made without analysing a wide range of influencing factors and at the same time prioritizing them. The prioritization of factors affecting the global environment using qualitative research was alsorarely studied over the last few years. MacCarthy and Atthirawong[15] prioritized such factors in their Delphi method. Global panel of experts investigated factors affecting international location decisions and the authors compiled the results in their paper.

Remer et al[16]. review the use of factors and present more than 75 costand location factor and 10 scale-up factor references to assist estimators in locating these data. Some precautions for using these factors are alsopresented.

The above literature review gives a generalized form for case specific problems developed in global and national environment. Most of the models found in literature were country specific[3,9,10,17] However there are many on global site location problems as well[1,8,11,13,18], Researchers either use single or hybrid approaches for the development of system. Very few papers focus on the influencing factors[15]. A significant research gap can be clearly seen in the area ofglobal decisionsfor the cement sector. There is a desperate need to implementthe decision support systemsfor corporate and strategic decisions of the global cement industry for its success in rapidly emerging economies of near future. The problem of global plant location solved by MCDM tools addressed here is one of the many such decisions.

RESEARCH METHODOLOGY AND MATHEMATICAL MODELLING

Formal interviews with the executive managers and sector development experts were conducted before finalizing priorities. Special characteristics like availability of lime stone in the specific country and per capita cement consumption are also crucial over and above the conventional global facility location factors. Fuel costs seemed to be an important factor under the category ofcosts. Most of the factors did not lose their ranking and they remained the same as suggested by MacCarthy[15]. The only difference was introduction of a new main factor named "Specific factors for cement plant location" and it was given top most place in the list.The main factors are: 1) Specific factors for cement plant location; 2) Costs; 3) Infrastructure;4) Labour characteristics; 5) Government and political factors; 6) Economic factors. These factors have been extensively used in literature. The sub factors remained the same as in Delphi Study by McCarthy (2003)for the cement plant location problem.

MATHEMATICAL MODELLING

The notations and abbreviations used in the development of mathematical model for the methodologies are given:

$\alpha_{12}, \alpha_{13}, \ldots\ldots \alpha_{nm}$ = Weights assigned to main factors w.r.t. eachother

ω_1 , ω_2 , ω_i = importance weights computed from comparison matrix

$\rho_1, \rho_2, \rho_3 \ldots\ldots \rho_n$ = weights computed for main factors

K = Alternative Country

λ_{ijk} = weight of alternative 'k' with respect to main and sub factors.

ψ_k = Composite weight of alternative 'K'

IC_i = Initial Investment Cost

FC_i = Fuel Cost

X_i = Units produced

EC_i = Energy Cost

LC_i = Labour Cost

SP_i = Sales Price

MAS = Minimum Acceptable Sales

LCAP = Lower Capacity Limit

UCAP = Upper Capacity Limit

M = An arbitrarily large number

Yi = Zero One variable (1 if selected and 0 otherwise)

cc_i = Consumption of cement per capita in country "i"

CC = Acceptable/Targeted value of Consumption of cement per capita

pc_i = Production cost per unit in respective country

PC = Targeted production cost

ic_i = Investment Cost in country "i"

IC = Targeted value of Investment Cost

f_i = Investment Cost in country "i"

F = Targeted value associated with infrastructure

l_i = Labour characteristics in country "i"

$L_=$ Targeted value associated with labour characteristics

g_i = Govt. Stability level in country "i"

G = Targeted value of Government Stability

d_c^+ ,d_c^- =Positive and negative deviations associated with targeted value of consumption of cement per capita

d_p^+ ,d_p^- = Deviations associated with targeted value of production cost

d_s^+, d_s = Deviations associated with targeted value sales

d_i^+ , d_i^- = Deviations associated with targeted value of investment cost

d_f^+ ,d_f^- = Deviations associated with targeted value of Infrastructure

d_l^+ , d_l^- = Deviations associated with targeted value of labour characteristics

d_g^+ , d_g^- = Deviations associated with targeted value of government stability

d^+_{cf} , d^-_{cf} = Positive and negative deviations associated with targeted value of weights for specific factors of cement plant location problem obtained from AHP solution.

d_w^+ ,d_w^- = Positive and negative deviations associated with targeted value of overall weights obtained from solution of AHP.

ANALYTICAL HIERARCHY PROCESS(AHP) MODEL

The AHP hierarchy is presented in Figure 1 with three levels as per nature of AHP[1]. Countries at level 3 are the alternatives to be chosen from.

The AHP comparison matrix for main factors will be,

$$\begin{bmatrix} 1 & \alpha_{12} & \alpha_{13} & \alpha_{14} & \cdots & \alpha_{1m} \\ 1/\alpha_{12} & 1 & \alpha_{23} & \alpha_{24} & \cdots & \alpha_{2m} \\ 1/\alpha_{13} & 1/\alpha_{23} & 1 & \alpha_{34} & \cdots & \alpha_{3m} \\ 1/\alpha_{14} & 1/\alpha_{24} & 1/\alpha_{34} & 1 & \cdots & \alpha_{4m} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 1/\alpha_{1m} & 1/\alpha_{2m} & 1/\alpha_{3m} & 1/\alpha_{4m} & \cdots & 1 \end{bmatrix} \tag{1}$$

This matrix is filled by pair wise comparison of each factor with respect to other corresponding factor. Hence the importance weight"ω" for each factor is computed from above matrix as;

$$\begin{bmatrix} \omega_1 \\ \omega_2 \\ \vdots \\ \omega_{m-1} \\ \omega_m \end{bmatrix} \tag{2}$$

Subject to,

$$\omega_i \geq 0 \text{and} \qquad \sum_{1}^{m} \omega_i = 1 \tag{3}$$

Hence ψ_k the composite weight of alternative 'k' can be represented as,

$$\psi_k = \sum_{i=1}^{n} \rho_i \sum_{j=1}^{n_i} \omega_{ij} \lambda_{ijk} \tag{4}$$

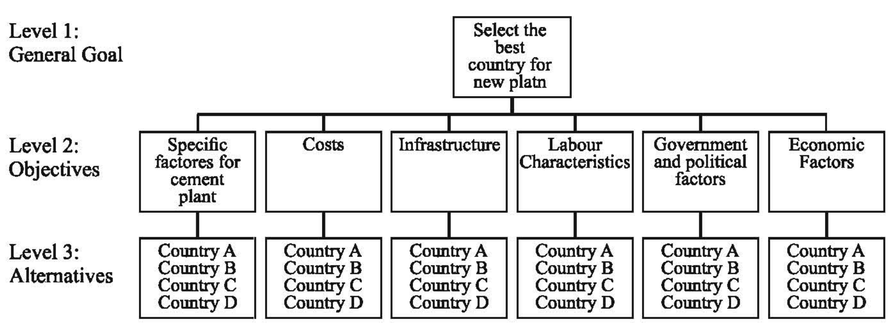

Figure 1: Hierarchy of AHP Model

LINEAR/INTEGER PROGRAMMING (LP) MODEL

The objective of this 0-1 mixed integer programming formulation is to determine countries to locate the new cement plant. The objective of the model is expressed as minimization of costs, which incorporates the different prices in different countries. The costs incorporated include investment, fixed, fuel, energy and labor costs. The general model built for cement plant location is mathematicallyexpressed as (notation and symbols have been explained earlier);

$$\text{MINIMIZE } Z = \sum_{i=1}^{n} IC_iY_i + \sum_{i=1}^{n} FC_iX_i + \sum_{i=1}^{n} EC_iX_i + \sum_{i=1}^{n} LC_iX_i \quad (5)$$

Subject to,

$$\sum_{i=1}^{n} SP_iX_i \leq MAS \text{ (Minimum acceptable sales/Capacity)} \quad (6)$$

$$\sum_{i=1}^{n} X_i > LCAP \text{ (Lower Limit of Capacity)} \quad (7)$$

$$\sum_{i=1}^{n} X_i < UCAP \text{ (Upper Limit of Capacity)} \quad (8)$$

$$\sum_{i=1}^{n} X_i - MY_i \leq 0 \ \forall i \in 1,2,3....n \quad (9)$$

$$\sum_{i=1}^{n} Y_i = 1 \ \forall i \in 1,2,3....n$$

$$X_i \geq 0$$

GOAL PROGRAMMING (GP) MODEL

The general model has a complex structure which is used for application of priorities from 1 to 7. Each priority used for the specific condition is explained in the form of mathematical model and notation/abbreviations have been defined:

Priority 1: The Country with higher per capita cement consumption

$$\sum_{i=1}^{n} cc_i\, Y_i - CC = d_c^+ - d_c^- \quad (10)$$

Priority 2: The Country with lower production cost per ton

$$\sum_{i=1}^{n} pc_i\, X_i - PC = d_p^+ - d_p^- \quad (11)$$

Priority 3: The country with higher sales

$$\sum_{i=1}^{n} SP_iX_i - MAS = d_s^+ - d_s^- \quad (12)$$

Priority 4: The country with minimum initial investment cost

$$\sum_{i=1}^{n} ic_i\, Y_i - IC = d_i^+ - d_i^- \quad (13)$$

Priority 5: The country with higher world ranking for infrastructure

$$\sum_{i=1}^{n} f_i\, Y_i - F = d_f^+ - d_f^- \quad (14)$$

Priority 6: The country with higher world ranking for laborcharacteristics

$$\sum_{i=1}^{n} l_iY_i - L = d_l^+ - d_l^- \quad (15)$$

Priority 7: The country with higher points for stability of Government

$$\sum_{i=1}^{n} g_iY_i - G = d_g^+ - d_g^- \quad (16)$$

$$\sum_{i=1}^{n} X_i - MY_i \leq 0 \ \forall i \in 1,2,3....n \quad (17)$$

$$\sum_{i=1}^{n} Y_i = 1 \ \forall i \in 1,2,3....n$$

$$\sum_{i=1}^{n} X_i > LCAP$$

$$\sum_{i=1}^{n} X_i < UCAP$$

$$X_i \geq 0$$

$$\text{MINIMIZE } Z = P_1\, d_c^- + P_2 d_p^+ + P_3\, d_s^- + P_4 d_i^+ + P_5 d_f^+ + P_6 d_l^+ + P_7\, d_g^- \quad (18)$$

HYBRID AHP+GP MODEL

In the hybrid models some variables from the AHP models were used as the top priority targeted goalin GP models. Other quantitative factors retained their priorities. Following were the goals in GP format;

Priority 1: The Country with higher weight obtained fromAHPfor specific factors of cement plant location

$$\sum_{i=1}^{n} w_{ci} - 1000 = d^{+}_{cf} - d^{-}_{cf} \quad (19)$$

The result of Eigen vector from matrix algebra of AHP can have a maximum value of one. However to make the case simple maximum value is converted to one thousand. All the weights are normalized to two/ three digits and their sum is equal to 1000 instead of one.

Priority 2: The Country with lower production cost per ton;

$$\sum_{i=1}^{n} pc_i X_i - PC = d_p^{+} - d_p^{-} \quad (20)$$

Priority 3: The Country with higher sales

$$\sum_{i=1}^{n} SP_i X_i - MAS = d_s^{+} - d_s^{-} \quad (21)$$

Priority 4: The country with minimum initial investment cost

$$\sum_{i=1}^{n} ic_i Y_i - IC = d_i^{+} - d_i^{-} \quad (22)$$

Priority 5: The country with higher world ranking for infrastructure

$$\sum_{i=1}^{n} f_i Y_i - F = d_f^{+} - d_f^{-} \quad (23)$$

Priority 6: The country with higher laborcharacteristics

$$\sum_{i=1}^{n} l_i Y_i - L = d_l^{+} - d_l^{-} \quad (24)$$

Priority 7: The country with higher stability of Government

$$\sum_{i=1}^{n} g_i Y_i - G = d_g^{+} - d_g^{-} \quad (25)$$

Priority 8: The country with higher weight from AHP results

$$\sum_{i=1}^{n} w_i Y_i - 1000 = d_w^{+} - d_w^{-} \quad (26)$$

The constraints set will be completed after following sets.

$$\sum_{i=1}^{n} X_i - MY_i \leq 0 \ \forall i \in 1,2,3....n \quad (27)$$

$$\sum_{i=1}^{n} Y_i = 1 \ \forall i \in 1,2,3....n$$

$$\sum_{i=1}^{n} X_i > LCAP$$

$$\sum_{i=1}^{n} X_i < UCAP$$

$$X_i \geq 0$$

$$\text{MINIMIZE } Z = P_1 d^{-}_{cf} + P_2 d_p^{+} P_3 d_s + P_4 d_i^{+} + P_5 d_f^{+} + P_6 d_l^{+} + P_7 d_g^{-} + P_8 d_w^{-} \quad (28)$$

DATA SPECIFIC MODEL SOLUTIONS

The capacity of plant,limitations of resources, global markets, prioritization of global factors and all other aspects regarding a global cement plant location have been discussed with a panel of experts including executives of cement industries, in addition to the available literature. Based on global markets and availability of raw material the decision was finalized that following countries should be analyzed: a) China; b) India; c) Pakistan; and d) Saudi Arabia. The reason for selecting these countries is the economic growth which is prime objective for them. Apart from striving for economic growth, the main criterion which the mentioned countries were selected for are; I) Consumption of cement per capita; II) Availability of raw material (Lime stone); III) Quality of raw material (Lime stone) and IV) Marketing Position with respect to the surroundings. The mathematical models developedin the previous sectionwerethen applied and mathematical routines coded in specific software. Specific factors for cement plant locationwere prioritized based on the recommendations of the panel of experts and the Delphi study[15] are in the following orders, 1) Availability of raw material (Lime stone); 2) Quality of raw material (Lime stone); 3) Consumption of cement per capita; 4) Marketing Position with respect to surroundings. Moreover thesub factors of cost were prioritized in the following order is; 1) Fuel Costs; 2) Energy Costs; 3) Investment Costs; 4) Raw material costs; and 5) Wage rates.

The significant data for the specific countries is collected from World Bank Organization and WTOweb sites.It is primarily based on statistical data developed by such organization. In most of the cases rankingsare calculated for countries. Table A in appendix is used as input data for selected methodologies.

MODELS ANALYSIS AND RESULTS

The collected data was analysed in models coded in respective software. Coming sections discuss the results obtained.

AHP MODEL IN EXPERT CHOICE®

AHP model developed in previous sectionis solved through Expert Choice® using the priorities of objectives[1]. The best country for cement plant location is the 'goal'. Criteria to achieve this goal are the "Objectives" in this hierarchical model.

The Bars in Figure 2 show the weights obtained by different alternatives based on input data. Saudi Arabia, apparently,comes out as the best option with a weight of 0.343. Other details of the solution are shown in Figure 2 and Table 1.

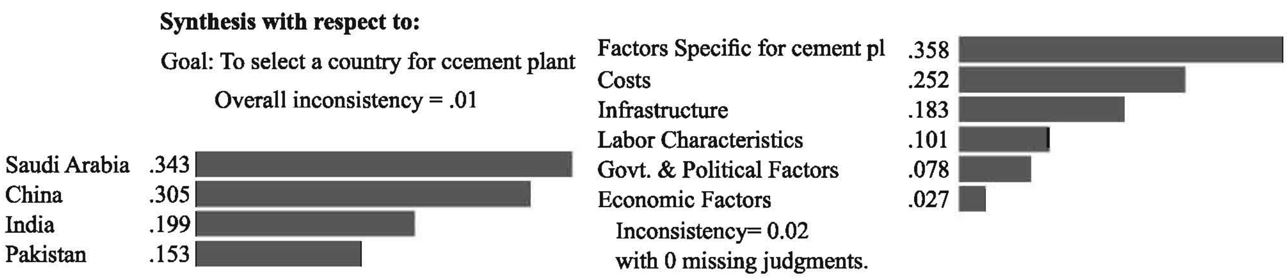

Figure 2: Calculated weights (Countries) and weights for each criterion.

Table 1: Calculated weights for alternative countries w.r.t. main criterion

Factors	Pakistan	India	China	Saudi Arabia
Cement Plant Factors	0.198	0.179	0.293	0.330
Costs	0.148	0.238	0.260	0.355
Infrastructure	0.095	0.155	0.333	0.417
Labour Characteristics	0.095	0.174	0.379	0.351
Govt. And Political Factors	0.106	0.253	0.401	0.241
Economic Factors	0.344	0.291	0.217	0.148

Table 2: Comparison of forced (hypothetical) results for countries

Alternatives	Minimum Cost for Year1 (M US$)	Production Capacity (Tons per year)	Receipts (M US$)
China	188	2	140
Pakistan	297	1.8	180
India	264	1.86	140
Saudi Arabia	366	1.8	207

Table 3: Calculation of weights for GP model priorities

Factors	Straight Ranks	Weight (n-ri+1)	Normalized Weight
Cement Specific Factors(d1N)	1	7	0.212
Costs1(d2P)	2	6	0.181
Costs2(d3P)	2	6	0.181
Sales(d4P)	4	4	0.121
Infrastructure(d5P)	3	5	0.151
Labour Characteristics(d6P)	5	3	0.090
Govt. and Political Factors(d7N)	6	2	0.060

LINEAR PROGRAMMING MODEL WITH LINGO®

The Linear Programming model developed has been coded in Lingo. China comes out as the best option due to minimum cost with production capacity of two tons and the receipts of US $ 140M.Table 2 represents the resultswhen binary variables Y_p, Y_i and$Y_s$taken, one by one,were given value equal to 1,

GOAL PROGRAMMING MODEL WITH LINGO®

The mathematical models developed previously are solved in Lingo®. The weight method of straight ranks is used to assign the priorities to respective goals. The goals are directly assigned rankings and then ranks are normalized as given in Table 3, where "n" represents the total number of criteria and "r" is straight rank of respective factors. These ranks are assigned to their relevant priorities in the minimizing objective function.China comes out the best option with one deviation from targets and this deviation is from production cost goal.

HYBRID (AHP-GP) MODEL IN LINGO®

In order to make the case simpler and compatible, the weights in Table 3 are normalized and presented in Table 4. Each value is multiplied by 1000 and hence fractions are removed. Some of this data will be used in the hybrid models derived previously.

Country selected is Saudi Arabia with four target deviations out of which two are related to AHP and they can be neglected as the normalized target is 1000 whichis impossible to be attained. Other two deviations are production cost and initial cost. Note that hybrid model gives a more satisfying solution as it has given importance to qualitative factors as well.

COMPARISON AND STABILITY RESPONSE ANALYSIS

The results obtained from the analysis of methodologies are presented in Table 5. These results are obtained by the first iteration of each model.From this analysis, it is evident that Linear Programming and Goal Programming are recommending China whereas AHP and hybrid model are suggesting Saudi Arabia as thebest alternative.

It is worth mentioning that linear programming is dealing with costs and production capacity limitations while AHP is considering all the factors. However, difference in GP+AHP model and the GP alone modelresults are more debatable to make a confidently reliable solution as both are using multiple constraints. Table 6 compares the details of GP and GP+AHP results.

The difference in current results demands to change the scenario in order to see the effects on the responses. It is therefore necessary to make several scenarios of the models to check stability of results.

RESPONSE OF MODELS FOR CHANGE OF PRIORITIES

The initial priorities, as discussed earlier, are based on

Table 4: Normalized weights for hybrid models

Factors	Pakistan	India	China	Saudi Arabia
Cement Plant Factors	198	179	293	330
Costs	148	238	260	355
Infrastructure	095	155	333	417
Labour Characteristics	095	174	379	351
Govt. And Political Factors	106	253	401	241
Economic Factors	344	291	217	148
Overall Result	153	199	305	343

Table 5: Comparison of results

Country Name	AHP	LP	GP	AHP+GP
Pakistan	N	N	N	N
India	N	N	N	N
China	N	Y	Y	N
Saudi Arabia	Y	N	N	Y

YES= Y; NO = N

Table 6: Goal Programming and Hybrid AHP+GP models

Methodology	Result	Production Capacity (M Tons/year)	Deviation from Production Cost Target (M $)	Deviation from Investment Cost Target(M$)
GP	China	2.286	14.28	0
AHP+GP	Saudi Arabia	1.8	15.6	95

Table 7: Comparison of results for different priority combinations

Priority Combinations	AHP	GP	AHP+GP
Cement Factors-Costs-Infrastructure	Saudi Arabia	China	Saudi Arabia
Cement Factors-Infrastructure-Costs	Saudi Arabia	China	Saudi Arabia
Costs-Cement Factors-Infrastructure	Saudi Arabia	China	China
Costs-Infrastructure-Cement Factors	Saudi Arabia	China	China
Infrastructure-Cement Factors-Costs	Saudi Arabia	China	Saudi Arabia
Infrastructure-Costs-Cement Factors	Saudi Arabia	China	Saudi Arabia

the Delphi study[15] and on recommendations of a panel of experts from cement sector. It is required to change the priorities in order to check the stability of models and to validate the results. The priorities of top three factors have been decided to be changed. The priorities are changed with respect to each other and hence six combinations are established. MS Excel® sheets have been usedto normalize the weights and conclude meaningful results. The LP model is unable to handle these combinations as it cannot deal multiple goals and prioritization of factors. Results are given in Table 7.

Results obtained from these six iterations for each methodology show that there is no effect of change in priorities of top three factors on results of AHP and GP models. AHP recommends Saudi Arabia whereas GP recommends China for all the combinations and does not give clear reason of difference in their results. However, the resultsfrom the hybrid model give a very clear clue to solve the issue.AHP model considers all the inputs as qualitative ones but the factor like limitation of resources such as capacity of plants and budget restrictions are beyond the scope of AHP. On the other hand LP alone gives a very good analysis regarding the limitations of resources but unable to solve the optimization problems involving qualitative factors and multi-objective decisions alternatives. Though GP modelling is an effort to deal with multi-objective decisions but the results show that the nature of modelling is quantitative and is normally based on goals with some numerical targets. Since the hybrid modelling deals with both of the factors, it recommends Saudi Arabia for all priority combinations except for the combinations in which costs were given the top priority.When the cost is given top priority, the hybrid model recommends China because of cheapest plant and hence the lowest initial investment cost.The results of AHP which are the in numerical form have been used in the hybrid model as quantitative targets. Since Saudi Arabia is stronger in cement specific factors, it is recommended by the hybrid model in all other combinations except for the combinations having costs on top priority.It seems that solution obtained by thehybrid methodology is more reliable.When analysisis carried out on input data, it appears that though initial investment cost is higher in Saudi Arabia as compared to China, theper ton production cost is lower in Saudi Arabia due to cheaperenergy costs. This has raiseda debatable issue and it was necessary to analyze the response of models by changing the costs.

RESPONSE OF MODELS WITH RESPECT TO CHANGE OF COSTS

The costs included in previous models were considered for one year as production capacity constraints have units of tons per year. The initial results by LP and GP

Table 8: Change of capacity and costs limitations Comparison/LP result

Period for Analysis	Results (LP)	Results (GP)	Results (GP+AHP)	Production Capacity	Total Cost (Million $ in period)	Deviations from Targets
(Years)	(Country Name)	(Country Name)	(Country Name)	--	--	
1	China	China	Saudi Arabia	2.28	197.7	NA
3	China	Saudi Arabia	Saudi Arabia	6.86	353	NA
5	China	Saudi Arabia	Saudi Arabia	11.42	508.6	NA
6	India	Saudi Arabia	Saudi Arabia	12.80	581	NA
7	India	Saudi Arabia	Saudi Arabia	14.93	643	NA
8	Saudi Arabia	Saudi Arabia	Saudi Arabia	14.40	694	NA
10	Saudi Arabia	Saudi Arabia	Saudi Arabia	18.00	788	NA
12	Saudi Arabia	Saudi Arabia	Saudi Arabia	21.60	881	NA
15	Saudi Arabia	Saudi Arabia	Saudi Arabia	27.00	1022	NA

Table 9: Details of results obtained from the GP Model Iterations

Period for Analysis	**Result**	**Production Capacity**	**DEVIATIONS FROM TARGETS**						
			Undesirable Deviations		**Desirable Deviations**				
(Years)	(Country Name)	(Million tons in period)	d2P	d3P	d1P	d4P	d5N	d6N	d7P
1	China	2.28	14.28	0	336	0	8	30	42
3	Saudi Arabia	5.4	88.8	100	552	141	15	19	25
5	Saudi Arabia	9	204	100	552	235	15	19	25
7	Saudi Arabia	12.6	319.2	100	552	329	15	19	25
10	Saudi Arabia	18	492	100	552	470	15	19	25
12	Saudi Arabia	21.6	607	100	552	564	15	19	25
15	Saudi Arabia	27	780	100	552	705	15	19	25
Total Deviations			2505.28	600	3648	2444	98	144	192

Table 10: Details of results obtained from the Hybrid model iterations

Period	Result	Production Capacity	**Deviations from Targets**							
			Undesirable Deviations				**Desirable Deviations**			
(Years)	(Country Name)	(Million tons in period)	d1N	d2P	d4P	d8N	d3P	d5N	d6N	d7P
1	Saudi Arabia	1.8	670	15.6	95	640	47	15	19	25
3	Saudi Arabia	5.2	670	131	95	640	141	15	19	25
5	Saudi Arabia	27	670	822	95	640	2305	15	19	25
8	Saudi Arabia	14.4	670	419	95	640	376	15	19	25
10	Saudi Arabia	18	670	534	95	640	470	15	19	25
12	Saudi Arabia	21.6	670	649	95	640	564	15	19	25
15	Saudi Arabia	27	670	822	95	640	705	15	19	25
Total Target Deviations			4690	3392	665	4480	4608	105	133	175

recommend China for all combinations because China is cheapest country for one year (initial investment) calculations. This was the only strong factor of China which dominated all other strengths of SaudiArabian alternative. It was therefore required to generate the results considering the capacity and costconstraints for more than one year.

AHP model being unable to deal such changes could not be utilized in this analysis. The hypothetical cost and capacity analysis was performed by calculating total cement produced at the end of each year cumulatively. The results obtained from several iterations are presented in Tables 8 to10.

Table 11: Comparison of total undesirable deviations

Nature of Deviations	GP	GP+AHP
Production Cost Deviations	2505	3392
Investment Cost Deviations	600	665
AHP weights for cement factors	N.A.	670
Overall AHP weights	N.A.	640

Table 12: Comparison of total desirable deviations

Nature of Deviations	GP	GP+AHP
Cement Consumption per capita	3648	N.A.
Receipts	2444	4608
Infrastructure	98	105
Labour Characteristics	144	133
Govt Stability & Political Factors	92	175

Due to lowest initial cost China is recommended once again by LP and GP models for period of one year (Fig.3). However as soon as we hypothetically increase the capacity constraint and analyze it for a period of three years, GP changes the result and recommends Saudi Arabia for all other iterations till fifteen years.

The hybrid methodology (GP+AHP) recommends Saudi Arabia for all iterations including the one year analysis which means that some benefits are neglected by GP alone model due to its multi-objective nature.

The unstable response of LP seems a bit unrealistic. It recommends three countries for different periods and hence introduces another acceptable alternative 'India' for an analysis period of six and seven years. Nevertheless, interestingly, it also recommends Saudi Arabia for all remaining iterations. This is a good finding for acceptance of results if capacity and costs are concerned for a period of more than five years. But recommendation for India for a very narrow input is unreliable. Tables 11and 12 provide more details of the results by three methodologies.

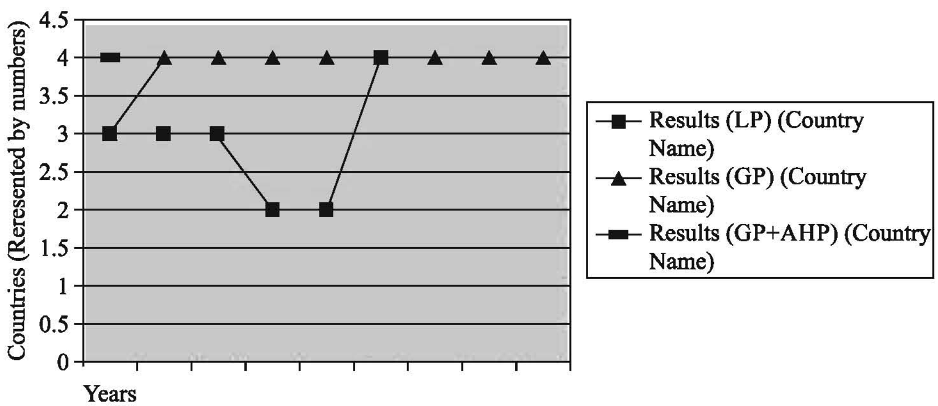

Figure 3: Results Comparison (capacity and costs limitations)

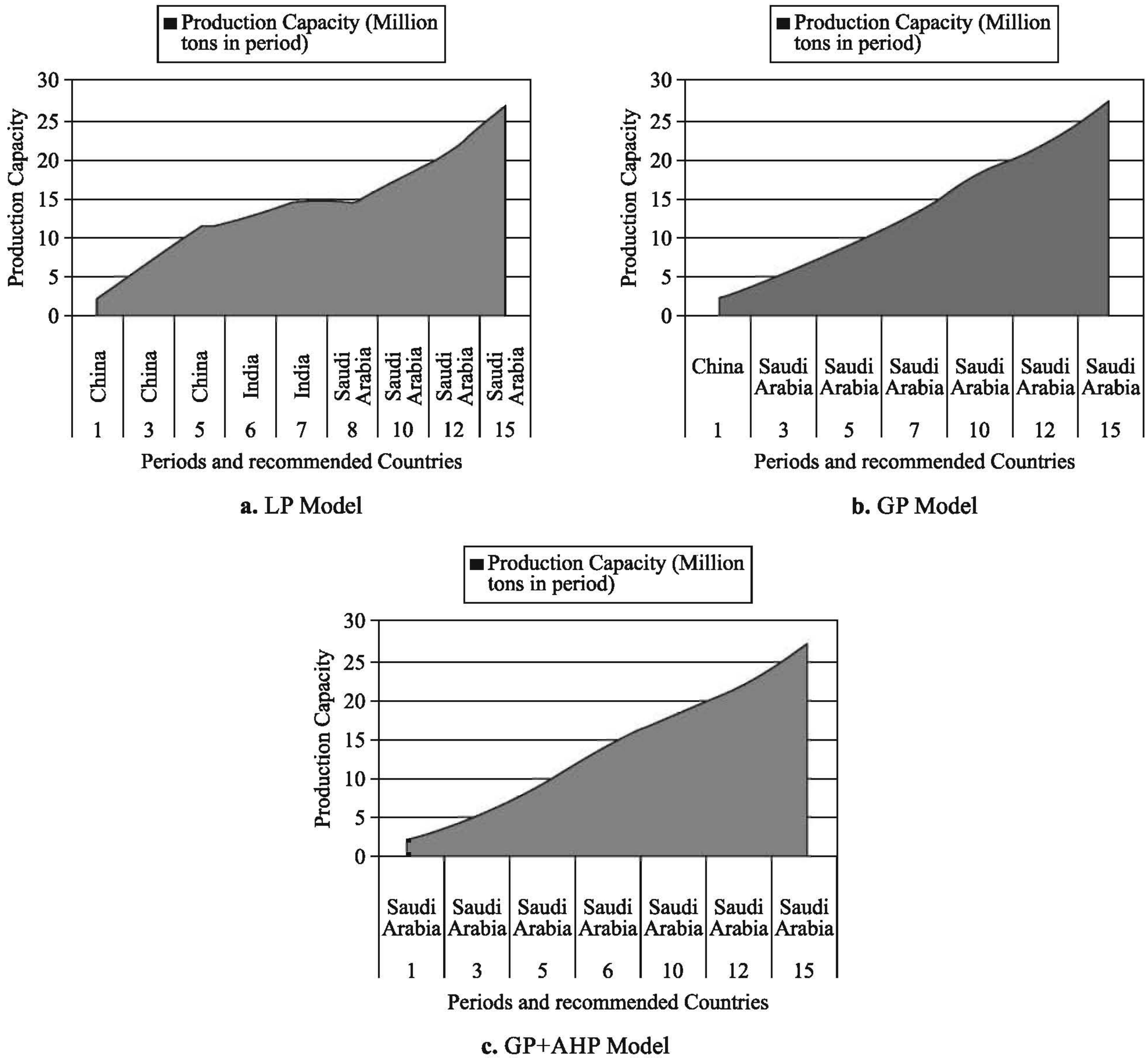

Figure 4: Change in output plant capacity with respect to periods

Figures 4 (a,b and c) compare the change in plant production capacity with respect to change of time periods. The fluctuations in LP results show that output is being analyzed very well according to limitations of resources but the results based only on one goal cannot be reliable.

Tables11 and 12 compare the total deviations from targeted goals in both multi-objective methodologies. There are fewer deviations from undesirable goals in GP results as compared to GP+AHP results. However, same is the case with desirable goals which means that both solutions are satisfying instead of being optimal ones.Therefore the results of hybrid model are simply more reliable as it considers more factors in its analysis.

CONCLUSIONS AND RECOMMENDATIONS

The Global Facility Location is a complex problem and normally there are many goals in decision maker's mind which should be achieved.Use of different methodologies with wide range of qualitative and quantitative decision variables has provided a more reliable and broader spectrum of results for a decision maker who can chose a country for a new cement plant location with more confidence.

In the first iteration LP and GP recommend China for new cement plant while AHP and the hybrid approaches advocated SaudiArabia as the best alternative.Stability analysis is also performed in which the effect of change in priorities to the response of the models has been analysed. The six combinations for three factorsare used as inputs for iterations performed. It is found that all models provide the same results with initial iteration except for the hybrid approach which recommends China when cost is given the top priority and Saudi Arabia for all other combinations. This difference in results demanded a detailed cost and capacity analysis necessary for acceptance of results.

Therefore, in second phase of the stability analysis, the total cost in all the alternatives is changed by changing capacity constraints and increasing the period of analysis upto fifteen years. The response of LP is unstable while GP becomes stable after period of three years by recommending Saudi Arabia.However combined AHP+GP models are very consistent by recommending Saudi Arabia for all iterations. The energy cost is the main reason behind the recommendations for Saudi Arabia. Itis neglected by the LP and GP when analysis is made for short period of time due to cheapest plant installation cost in China.It is apparent that hybrid model includes both the quantitative and qualitative factors which make results more reliable. However a decision maker should also be careful about limitations of available resources if he is making an analysis for a shorter period of time as it may be neglected by the hybrid model. The complex problem of global facilitylocation ismulti-objective in nature and requires analysis for longer time periods; hence the result of hybrid methodology which consistently recommends Saudi Arabiais provedto be acceptable. Results obtained from other methodologies presented here have also added confidence to decision makers for selecting Saudi Arabia with broader range of selection criteria

It is recommended to modify the models to make them able to deal with dynamic priorities with respect to time. Different world trade regions can also be analyzed for the globalization of cement sector.

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APPENDIX

Table A: Table A Collected Data for the Factors

	Measure	Pakistan	India	China	Saudi Arabia	Data Sources
	Infrastructure	72	67	52	45	Global Competitiveness Index (Ranking with respect to Infrastructure) [21]
Labour characteristics data	Quality of labour force	113	96	55	66	Labour Market Efficiency (GCI Ranking) [21]
	Availability of labour force	10	2	1	61	Labour Force (Wikipedia Ranking) [22]
	Motivation of workers and work force management	136	128	81	61	Human Development Index (Wikipedia Ranking) [23]
	Attitudes towards work and labour turnover	136	128	81	61	Human Development Index (Wikipedia Ranking) [23]
Data for sub factors of Cost	Fuel Cost (US$ per ton)	23	19	19	11	Calculated from the data provided by sr. managers of cement factories and the data collected from web resources mentioned in references
	Energy costs (US$ per ton)	10	8	8	5	-do-
	Fixed costs (Million US$)	235	210	120	320	-do-
	Wage rates (US$ per ton)	1.5	2	7	10	Calculated from different internet resources mentioned in references
Govt. and political factor	Record of government stability	-1.26	-0.84	0.22	0.05	Kaufmaun, Political Stability (-2.5 to 2.5) [24]
	Attitude of government to Inward investment	57	29	7	45	Foreign Direct Investment Index (Ranking) [25]
	Government structure	7	7	2	7	Global Freedom(1 for best, 7 for worst) [26]
Specific Factors for cement plant location	Availability of raw materials	A (High)	B (Medium)	A (High)	A (High)	Ranking decided upon recommendations of experts from cement industry
	Quality of Raw Material	A (High)	A (High)	A (High)	A (High)	-do-
	Consumption of cement per capita (Kg/annum)	120	113	589	805	International Cement Conference 2005 at SingaPur [20]
	Marketing Position (Interior)	B (Medium)	A (High)	A (High)	B (Medium)	Ranking decided upon recommendations of experts from cement industry
	Marketing Position (Exports)	A (High)	C (Low)	C (Low)	B (Medium)	-do-
Economic Factors Data	Tax structure and tax incentives	25.8	19.6	19.9	2.1	% of total profit (doingbusiness.org) [27]
	Custom Duties	8.78	17.02	7.45	46.27	% of custom duties in tax revenue (nationmaster.com) [28]
	Tariffs	92	48	34	35	GCI (Ranking) [21]
	Financial Incentives	110	121	111	62	World Economic Freedom (Ranking) [29]
	Strength of currency against us dollar	68	43	7	3.8	Currency Exchange Rates in May 2007
	Business climate	76	120	83	23	Ease of Doing Business Index (Wikipedia Ranking) [30]