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An AHP-Delphi Multi-Criteria Decision Making Model with Application to Environmental Decision-Making

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Abstract
Today, the advantage of biotechnology, especially from an environmental aspect, is undeniable compared to other technologies. Kimia Gharb Gostar Industries Company (KGGICO) - the largest producer of citric acid in the Middle East, is one of the companies that applies biotechnology. Citrogypsum is a by–product of citric acid production and is considered a valid residuum of this company. In this paper, acid citric production and condition of citrogypsum production in the company were introduced besides the definition of citrogypsum production and its applications around the world. Based on this information and the evaluation of present conditions regarding Iran's demands for citrogypsum, the best priority was introduced, and strategy selection and proper programming emphasized for self-sufficiency. The Delphi technique was used to elicit expert opinions about the criteria for evaluating the usages. The criteria identified by the experts were profitability, capacity of production, the degree of investment, marketable, production ease, and time of production. The Analytical Hierarchy Process (AHP) and Expert Choice software were used to compare the alternatives based on the criteria derived from the Delphi process.

Keywords: *Analytical Hierarchy Process, AHP, Delphi, Multi-Criteria Decision Making, Citrogypsum*

1- Introduction
Citric acid (H_3Cit) is of dominant industrial importance because it is a useful product, that has been widely used in dairy, medicine, and biochemical industries [1]. Until the 1920s, all commercial Citric acid (CA) was produced from lemon and lime juice. CA can be produced by fermentation process using a species of microorganisms namely Aspergillus Niger, a fungus which was used commercially for the first time in 1923 [2]. Now, most CA is produced by fungal (A. Niger) fermentation. Chemical synthesis of citric acid is possible, but it is no cheaper

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than fungal fermentation. However, a small amount of CA, approximately less than 1% of total world production, is still produced from citrus fruits in Mexico and South America where citrus fruits are available economically. The estimated world production of CA was reported as 350 000 tons/year in 1986. However, the world market requirement of CA in 1992 was reported to be around 500 000 tons/year [3]. In 2002, CA production by fermentation was estimated to be around 7.0 $\times 10^5$ tons/year [4]. CA plants are mainly produced by mycological fermentation of crude sugar solutions such as molasses. In order to separate CA from impurities such as proteins and sugars, it is precipitated with lime into calcium citrate and washed. Pure CA is then recovered by acidification with sulphuric acid and filtered off from the formed Gypsum ($CaSO_4.2H_2O$) [5]. Acid calcium sulfate suspensions are formed in sulfuric acid extraction of CA ($C_6H_8O_7$) from calcium citrate $Ca_3(C_6H_5O_7).4H_2O$. Citrogypsum is a by–product of CA production. The points in which calcium sulfate dehydrate ($CaSO_4$. $2H_2O$) and hemihydrate ($CaSO_4.0.5H_2O$) coexist in equilibrium are commonly found by studying their solubility and determining graphically the intersection points of the solubility isotherms of gypsum and calcium sulfate hemihydrate, or by comparing the water vapor pressures over the corresponding solutions with the dissociation pressure of the reversible reaction [6]:

$$CaSO_4.2H_2O(s) \rightleftharpoons CaSO_4.0.5H_2O(s) + 1.5\ H_2O\ (vapor) \tag{1}$$

Generally there are two types of gypsum: hemihydrate (HH) and dihydrate (DH). They can be clearly differentiated despite the structural similarities between gypsum or DH, and the partly dehydrated bassanite or HH [7]. The industrial dehydration and rehydration of different calcium sulphates are shown in Fig. 1.

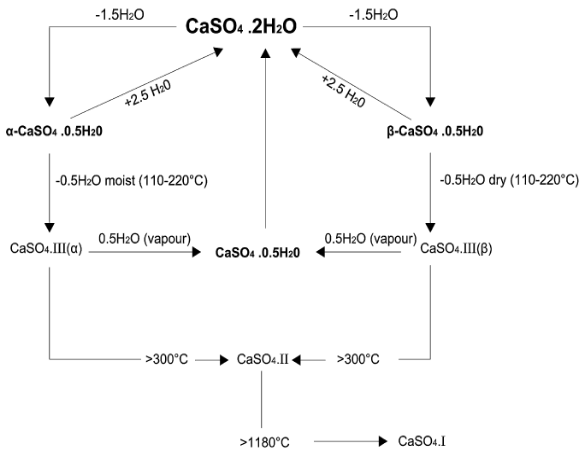

Figure 1. Different modifications of $CaSO_4xH_2O$ (x= 0.0-2.0)

For specific usage of citrogypsum, many reactions can be carried out on it e.g., an attempt was made by Kostic-Pulek et al. [8] to provoke the dehydration reaction of citrogypsum using an unheated sulphuric acid solution at different concentrations (under atmospheric pressure); alpha–hemihydrate was obtained as the product.

High-technology/knowledge-intensive industries have become of increasing importance as sources of job growth and revenue to communities to develop their economies. The communities believe these industries can help them to be as economically vigorous as possible. However, although high-tech industries such as biotechnology are coveted as drivers of economic development, the local development impact of these clusters of regional innovation is not entirely positive. This is especially true with regard to the impact on low and semi-skilled populations [9].

Fig. 2 shows the process of citric acid production in KGGICO schematically.

Despite the advantages discussed above, unfortunately, at present KGGICO disposes citrogypsum as a waste material. Due to the many environmental problems related to citrogypsum disposal, the company invests significant amounts of money to reduce these problems without converting citrogypsum into a valuable product. The focus of this study is to avoid the environmental problems and to determine the economical use of capital investments. After recognizing the type of citrogypsum and its applications around the world, and based on the evaluation of present conditions regarding Iran's demands for citrogypsum, the best priority was introduced and the focus was on strategy selection and proper programming for self-sufficiency. The Delphi technique was used to elicit expert opinions about the criteria for evaluating the usages. The Analytical Hierarchy Process (AHP) and Expert Choice software were used to compare the alternatives, based on the criteria derived from the Delphi process.

2- Experimental

Citrogypsum was subjected to the classical chemical, qualitative IR (Perkin Elmer 597), and microscope (American Optical-Stereoscopic Microscope). Shimadzu 6650 atomic absorption spectrometer, equipped with a deuterium lamp background correction system, a GFA-EX7 graphite furnace, and an ASC-6650 autosampler, was used in the determinations. The experiment was performed in a laboratory's charge reactor with perfect mixing (n = 600 rpm) based on the following procedures [8]:

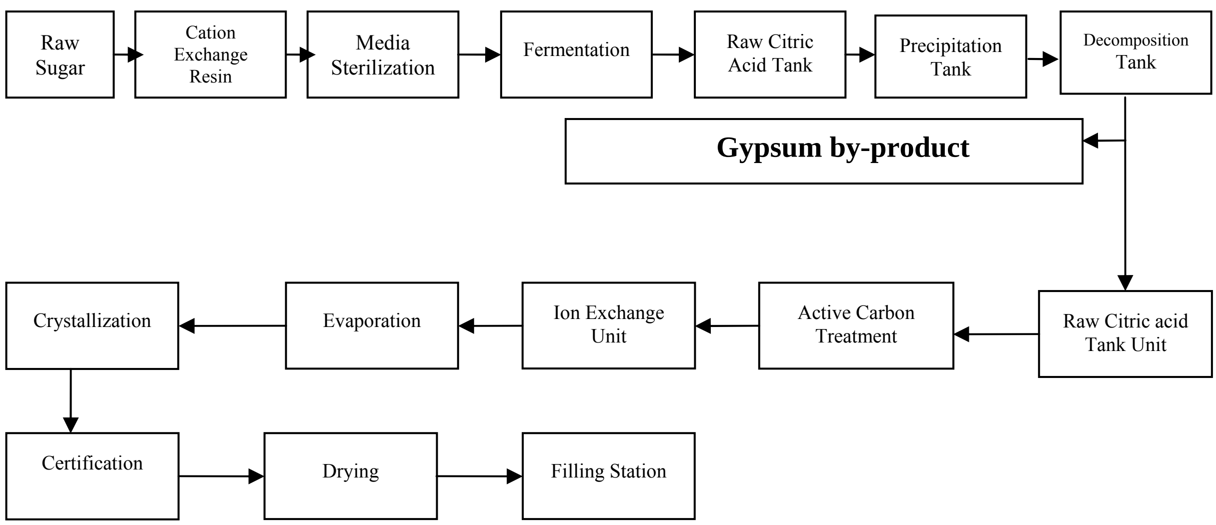

Figure 2. Schematic of the citric acid production process in Kimia Gharb Gostar Industries Company

Different quantities of citrogypsum (2, 5, 10, 20, 30, 40 grams) were suspended in an equal volume (40 cm^3) of sulphuric acid solutions of different concentrations (2.5, 5, 10, 15, 20, 30, 40 wt. %) and stirred for a predetermined period. The product was separated from the liquid phase by vacuum filtration, rinsed in water, dried at 105 ^oC, and examined in qualitative IR, microscopic, and DT analyses (type AMINCO). The contact time of the phases, solution, and citrogypsum was prolonged until the formation of hemihydrate. In case the hemihydrate was not formed or the product being a mixture of hemihydrate and dihydrate, the phase-contact time was prolonged to three hours. The results of the classical chemical presented in Table 1 indicate a pure citrogypsum substance which can be directly used in alphahemihydrate production without any pretreatment.

3- Alternative

Total global consumption of gypsum in 2003 was estimated to be around 150 million metric tons. Calcined products are not dominant; however, worldwide more than half of the gypsum is used in cement and concrete. The use of calcined gypsum in board products is increasing, particularly in industrialized countries, now accounting for about one-third of all use. However, use in cement and concrete, particularly in developing countries in the Middle East and Asia, will continue to be the primary market. Like in the U.S., the use of FGD gypsum worldwide is increasingly replacing the use of mined gypsum. Compared to the U.S., Europe has a longer history with management of FGD products, dating back to the late 1970s. ECOBA tracks FGD gypsum use in 15 European countries. Total production and utilization rates of FGD gypsum in 2003 were similar to those in the U.S., at 11.3 million metric tons and 71%, respectively. Germany produces by far the largest amount of FGD material; roughly half of the total output. The highest volume use was in gypsum board and plaster (58%), followed by reclamation (17%), self-leveling floors (15%), cement (7%), and blocks (3%) (Fig. 3). Reclamation, self-leveling floors, and gypsum blocks are uses that were not listed in the ACAA statistics for the U.S. They may represent markets for further exploitation [10].

Table 1. Classical chemical analysis of unwashed citrogypsum

component	ignition loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
(wt.%)	17.89	0.36	0.20	0.12	32.36	-	47.92

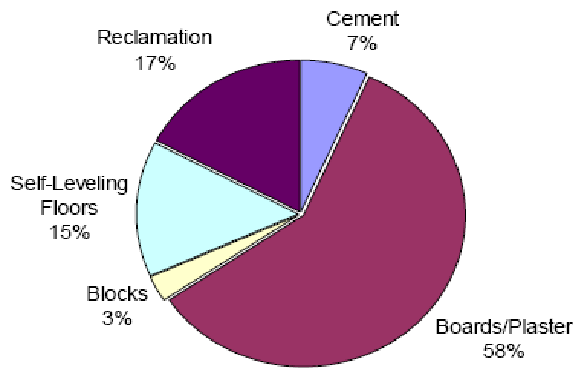

Figure 3. FGD gypsum use in Europe

3.1-Cement

In the cement industry, natural gypsum ($CaSO_4.2H_2O$) is added during grinding of Portland cement to delay the rapid reaction between C_3A ($3CaO.Al_2O_3$) and water and to regulate cement setting properties. Gypsum dehydration and formation of hemihydrate occur in industrial cement mills, which have a diverse effect on setting and compressive strength depending on the composition of the setting retarder. The extent of dihydrate conversion to hemihydrate depends on the temperature of the clinker and the relative humidity within the mill. The formation of the hemihydrate form of calcium sulfate dihydrate has a profound regulatory effect on the setting and strength performance of the cement partially replaced with FGD gypsum [11].

3.2- Plaster

Plaster is a dry powdered form of calcium sulfate hemihydrate (calcined gypsum). When mixed with the appropriate amount of water, plaster rehydrates and hardens. Historically, plaster was used to form interior wall surfaces by spreading it over a structure formed of wooden laths, mesh, or metal. In the U.S., the use of plaster for walls has been almost entirely replaced by the use of wallboard. A significant advantage of both plaster and gypsum wallboard in building construction is that these materials retard fire spread due to the water in their crystalline structure. Plaster has a variety of other minor uses including specialty products, sculptures, medical casts, industrial molds, and decorative trim [11].

3.3- Dental

Dental plaster is an unmodified hemi-hydrate gypsum plaster similar to plaster of Paris, but much more finely ground and generally produced from pure gypsum to produce a very good white colour. Dental plaster is generally used for dental surgery, but it is also used in the painting and decorating trade [11].

3.4- Wallboard

Prefabricated products command the lion’s share of the gypsum market, accounting for nearly 30 million metric tons, or 85%, of gypsum products. Wallboard (here refers to a wide variety of board products) consists of a layer of plaster sandwiched between two sheets of cardboard. After calcining, slurry of stucco (hemihydrate), foam, and other additives are blended in a mixer. Set retarders may be added to the mixer to prevent premature hardening of the plaster. The slurry is then placed between two continuously moving sheets; one above and one below, and allowed to harden, forming the board. As the material hardens, gypsum crystals form and bond to the cardboard. After hardening, the still-wet boards are sent to a dryer, where additional moisture is removed for about 45 minutes. After drying, the boards are cut to lengths typically ranging from 8 to 14 feet. There are many types of board for different applications. They can vary in thickness, strength, fire retarding capability, durability, and moisture resistance [11].

4- Analytical Hierarchy Process (AHP) application

The multiple criteria decision making (MCDM) methods are frequently used to solve real world problems with multiple, conflicting, and incommensurate criteria. MCDM problems are generally categorized as continuous or discrete, depending on the domain of alternatives. Hwang and Yoon (1981) [12] have classified the MCDM methods into two categories: multi-objective decision making (MODM) and multi-attribute decision making (MADM). MODM has been widely studied by means of mathematical programming methods with well-formulated theoretical frameworks. MODM methods have decision variable values that are determined in a continuous or integer domain with either an infinitive or a large number of alternative choices, the best of which should satisfy the DMs constraints and preference priorities [13,14]. MADM methods, on the other hand, have been used to solve problems with discrete decision spaces and a predetermined or a limited number of alternative choices. The MADM solution process requires inter and intra-attribute comparisons and involves implicit or explicit tradeoffs [12]. Analytic Hierarchy Process (AHP) is a MADM approach that simplifies complex and ill-structured problems by arranging the decision attributes and alternatives in a hierarchical structure with the help of a series of pairwise comparisons.

AHP is one of the most popular and powerful methods for group decisionmaking used in project selection, and AHP is a multi-criteria decision-making approach that simplifies complex, ill-structured problems by arranging the decision factors in a hierarchical structure. The AHP is a theory of measurement for dealing with quantifiable and intangible criteria that has been applied to numerous areas, such as decision theory and conflict resolution [15]. Project evaluation is usually a team effort, and the AHP is one available method for forming a systematic framework for group interaction and group decision-making, [16] and [17] describe the advantages of AHP in a group setting as follows: (1) both tangibles and intangibles, individual values, and shared values can be included in an AHP-based group decision process; (2) the discussion in a group can be focused on objectives rather than alternatives; (3) the discussion can be structured so that every factor relevant to the discussion is considered in turn; and (4) in a structured analysis, the discussion continues until all relevant information from each individual member in a group has been considered and a consensus choice of the decision alternative is achieved. A detailed discussion on conducting AHP-based group decision-making sessions including suggestions for assembling the group, constructing the hierarchy, getting the group to agree, inequalities of power, concealed or distorted preferences, and implementing the results can be found in [18] and [19]. For problems with using AHP in group decisionmaking, see Islei et al. (1991). AHP method requires the pre-selection of a countable number of alternatives and the use of a countable number of quantifiable (conflicting and noncommensurable) performance attributes (criteria). The attributes (criteria) may indicate costs and benefits to a DM. A larger outcome always means greater preference for a benefit or less preference for a cost criterion. After inter and intra-comparison of the alternatives with respect to a given set of performance attributes (criteria), implicit/explicit trade-offs are established and used to rank the alternatives [20]. The AHP method is selected for its specificity, which offers a certain freedom to a DM to express his preferences for particular attributes (criteria) by using the original AHP measurement scale. The AHP method does not require such explicit quantification of attributes (criteria), but it needs specific hierarchical structuring of the MCDM problem. The method itself then generates the weights of the criteria by using the AHP measurement scale according to a specified procedure. Under such circumstances, a comparison of the results from such different methods applied to the same problem appears to be very interesting and challenging from both academic and practical perspectives. In the next sub-sections, the basic structures of three MCDM methods and the procedures for assigning weight to the attributes (criteria) are described [21]. Saaty [22-24] developed the following steps for applying AHP:

1- Define the problem and determine its goal,
2- Structure the hierarchy with the decision-maker's objective at the top with the intermediate levels capturing criteria on which subsequent levels depend and the bottom level containing the alternatives, and
3- Construct a set of $n \times n$ pair-wise comparison matrices for each of the lower levels with one matrix for each element in the level immediately above. The pairwise comparisons are made using the relative measurement scale in Table 2, Saaty [25-27]. The pair-wise comparisons capture a decision maker's perception of which element dominates the other.

Table 2. Pair-Wise Comparison Scale for AHP Preference

Numerical rating	Verbal judgments of preferences
9	Extremely preferred
8	Very strongly to extremely
7	Very strongly preferred
6	Strongly to Very strongly
5	Strongly preferred
4	Moderately to strongly
3	Moderately preferred
2	Equally to moderately
1	Equally preferred

4- There are n (n-1)/2 judgments required to develop the set of matrices in step 3. Reciprocals are automatically assigned in each pair-wise comparison.
5- The hierarchy synthesis function is used to weigh the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.
6- After all the pair-wise comparisons are completed, the consistency of the comparisons is assessed by using the eigenvalue, λ, to calculate a consistency index, CI:

CI = (λ-n)/ (n-1) (1)

here n is the matrix size. Judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value in Table 3. Saaty [28] suggests that the CR is acceptable if it does not exceed 0.10. If the CR is greater than 0.10, the judgment matrix should be considered inconsistent. To obtain a consistent matrix, the judgments should be reviewed and repeated.

7- Steps 3-6 are performed for all levels in the hierarchy [28].

4.1- Group AHP method

While AHP can be used to capture the priorities of individual decision participants, it is necessary to combine these individual assessments into a consensus. To aggregate individual AHP judgments into a group decision, there are two perspectives.

4.1.1- Aggregation of individual judgment

In this view, a group decision matrix is constructed from the unique matrix of each decision participant. An element of this matrix (a_{ij}^G) is calculated using a geometric average of the elements from each unique matrix,

$$a_{ij}^G = \left\{ \prod_{K=1}^{n} (a_{ijk})^{\beta_k} \right\}^{\frac{1}{\sum \beta_k}} = \left\{ \prod_{K=1}^{n} (a_{ijk})^{\beta_k} \right\} \ , i, j = 1,\ldots,m \ , \quad K = 1,\ldots,n \qquad (2)$$

Where β_k and a_{ijk} are the importance and efficiency of the K decision and are elements of the K matrix, respectively [29].

4.1.2- Aggregation of individual priorities (AIP)

In this approach, the order of the decision weights for each decision alternative for the *K* decision (W_i^k), *K*=1….*n*, where n is the number of decision makers, is calculated and a group decision weight (W_i^G) for the alternative is constructed:

$$W^G = (W_i^G) \ ; W_i^G = \prod_{K=1}^{n} (w_i^K)^{\beta_K} \quad i = 1,\ldots,m \qquad (3)$$

Where β_k indicates the amount and importance of the effectiveness of *K* decision, and W^G matrix indicates the aggregation weight of a single judgment with respect to each alternative.

In both approaches, each individual judgment affects the final judgment β_k, so that:

$$\sum_{K=1}^{n} \beta_k = 1 \qquad (4)$$

After aggregating the individual judgments, matrices with the same dimensions as the unique individual matrices are constructed in which the local and final weights as well as the inconsistency of each matrix and total inconsistency are calculated with the same basic AHP method [29].

Table 3. Average Random Consistency

Size of Matrix	1	2	3	4	5	6	7	8	9	10
Random Consistency	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

5- The Procedure

5.1- Utilizing Delphi process

The Delphi method has been a popular tool in information systems research because the process increases the confidence with which researchers can use the results in subsequent studies and managers can make decisions based on the information gathered using this method. Researchers employ this technique primarily in cases where judgmental information is indispensable. The Delphi technique has been used to: predict technological developments [30], identify issues affecting health care administration [31-32], assess interventions and policies in the mental health industry [18], construct a model for project funding decisions at the National Cancer Institute [19], evaluate the strategic importance of jobs in pay rate decisions [20], evaluate emerging directions in information systems management [21], and assess strategic responses to threats from global terrorism [22]. A key advantage of Delphi is that it avoids direct confrontation between the participating experts [23]. While there have been many variations in practice, the Delphi method consists of three essential processes that achieve information exchange among a group of DMs without introducing the potential biases of interpersonal interaction. The first process is to collect judgments, along with the underlying rationales, from individuals who are knowledgeable about an issue by questioning them individually. The second process is to collate and statistically summarize the individual judgments and rationales without revealing the identity of the individuals. The third process is to feed back the collated information to the DMs and ask them to reconsider their judgments. This sequence of collating, feedback and revision is repeated over several rounds until further repetitions produce practically no changes in individual judgments.

Both Delphi and AHP assume knowledgeable DMs [24]. Therefore, a careful selection of the participants for the DM group is important. This issue is discussed by Brockoff [25] and Preble [26]. The experts who were selected to participate in this study include university professors and company experts who are closely related to the industries such as cement production instruments manufacturers. While the experts in these groups are knowledgeable about the citrogypsum issues, they were provided with the most recent research results and statistical information about the citrogypsum produced by KGGICO.

After identifying knowledgeable experts, the next step was sending questionnaires to elicit the experts' opinions about the factors affecting the usage of citrogypsum of KGGICO. The first questionnaire required the participants to identify the factors they thought were most important in selecting a site. A comprehensive and mutually exclusive list was collated from the responses. The second questionnaire included the list generated from the initial responses and requested the experts to check those factors they considered to be important. Table 4 summarizes the 27 responses to the second questionnaire.

The ability of DMs to make comparisons consistently declines precipitously as the number of items exceeds five. Consequently, it is important that DMs focus on the most important factors. In this case, the first six

Table 4. Number and Percentage of Experts Selecting Criteria as Important

No.	Criteria	Number (%) of experts that select the criteria as important			
		Researchers	University Experts	Company Experts	Total
1	Profitability	3 (11.11%)	12 (44.44%)	7 (25.93%)	22 (81.48%)
2	Capacity of production	3 (11.11%)	10 (37.03%)	8 (29.63%)	21 (77.78%)
3	The degree of investment	3 (11.11%)	8 (29.63%)	5 (18.52%)	16 (59.26%)
4	Marketable	3 (11.11%)	7 (25.93%)	5 (18.52%)	15 (55.56%)
5	Production ease	3 (11.11%)	6 (22.22%)	4 (14.81%)	13 (48.15%)
6	Time production	3 (11.11%)	6 (22.22%)	2 (7.41%)	11 (40.74%)

factors were identified as important by 60% of the experts. These six factors were included as criteria:

1, 2 and 3. Profitability (P), Capacity of production (CP), and the Degree of investment (DI): High P, CP, and DI are three positive factors that would facilitate the rate of citrogypsum consumption.

Marketable (M): Considering the importance of Marketable, the existence of purchasers would have a positive effect on the selling of product.

5 and 6. Production ease (T) and Time production (TP): Obviously the ease of production and less time for production would contribute to the efficiency of production and distribution.

Then, there is a 20% decline for the next criterion so that less than a majority of the experts designated it as important. In addition, factors six through nine are not relevant to the particular circumstances in citrogypsum of KGGICO, thus they were excluded from the decision process.

5.2- Application of expert choice software to facilitate the calculations

Expert Choice [33] provides significant support for DMs faced with solving complex problems involving the evaluation of alternative courses of action on qualitative as well as quantitative criteria [34-35]. The software helps a DM to structure a complex problem as a hierarchy of criteria and alternatives. Then, the DM is guided through a series of simple pairwise comparisons to solve the problem. While Expert Choice is powerful and intuitive, it is also easy to use. Therefore, the solution is more likely to reflect the expertise of the DM while minimizing interference from the program and the computer.

After identifying knowledgeable experts, cases of citrogypsum usage in other industries are being considered as an alternative for the citrogypsum of KGGICO. The alternative site locations and their designations in the hierarchy are: Cement (C), Plaster (P), Dental (D), and Wallboard (WB).

Fig. 4 presents the hierarchical structure of the problem. The six criteria identified in the Delphi process are the second level of the model. The citrogypsum usage cases are in the third level below the criteria on which the evaluation will be based on.

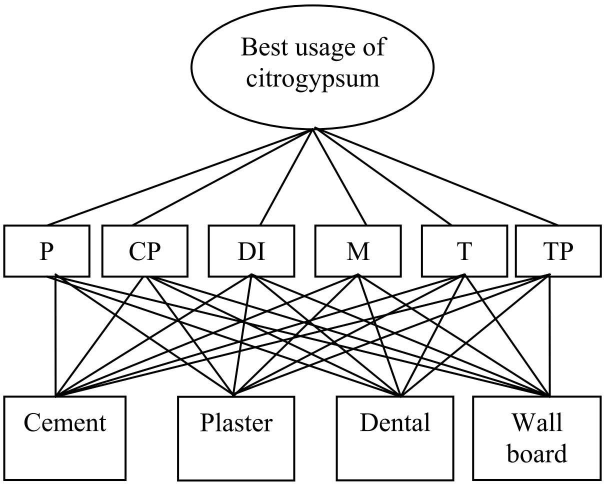

Figure 4. A hierarchal representation of the problem with five criteria and six alternatives

6- Results

Each of the participants in the project used Expert Choice to assess the relative importance of the criteria and to evaluate the priority of alternative usage cases. Pairwise comparisons are at the core of the AHP technique. At each level of the hierarchy below the goal, a DM is asked to compare each possible pair of factors (c_i and c_j) and to provide judgments on the relative importance of each. Each expert was asked to make pairwise comparisons between each possible pair of criteria. These judgments were input to Expert Choice. As described in the Appendix, once the pairwise comparison matrix at a given level of the hierarchy is complete, Expert Choice calculates the relative weights for the various factors at that level. For this expert P was the most important criterion while TP was assigned the least weight. In addition, Expert Choice computes an inconsistency ratio (IR) for each DM and encourages DMs whose IR exceeds 0.10 to reconsider their pairwise judgments. E.g. if an expert rates TP as two times more important than DI, and two times more important than CP; then logically for that expert, DI and CP should be equally important. However, e.g. if in a pairwise comparison between these two criteria, the expert declares CP to be three times more important than DI, a substantial inconsistency has occurred and the calculated IR would be greater than 0.10. Expert Choice would encourage the DM to reconsider all of the underlying pairwise comparisons, and after a few trials, the DM should arrive at an acceptable level of consistency. Among the experts participating in this project, the largest IR for the initial comparison of the criteria was 0.03 (<0.10). This level of inconsistency is very low and is indicative of the meaningfulness of the criteria to the DMs. After assigning weights to the criteria, the next task for the experts was to evaluate the alternatives on these criteria. As before, the experts made comparisons between pairs of alternatives. The EC output for these comparisons is presented in Fig. 5.

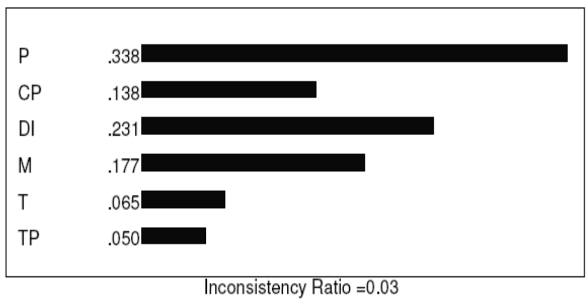

Figure 5. The relative weights with respect to GOAL

While there has been some criticism of AHP in the operations research literature, Harker and Vargas [35] and Saaty [16] have shown that AHP does have an axiomatic foundation. The cardinal measurement of preferences is fully represented by the eigenvector method, and the principles of hierarchical composition and rank reversal are valid. On the other hand, Dyer [36] has questioned the theoretical basis underlying AHP and argues that it can lead to preference reversals based on the alternative set being analyzed. In response, Saaty [17] explains how rank reversal is a positive feature when new reference points are introduced. In the citrogypsum usage decision, the geometric aggregation rule is used to avoid the controversies associated with rank reversal [27,35,36]. When all the comparisons between criteria and alternatives had been made by each expert, geometric averaging of the individual comparisons was used to synthesize the criterion weights and alternative priorities for the expert group. The EC output from all the AHP processes is presented in Fig. 6(a), (b). The results reveal that P and C were the site preferred by the experts.

7- Discussion and conclusion

Sensitivity analysis was used to investigate the stability of the alternatives' assigned priorities to changes in the relative importance of the criteria. For example, marketable is not reliably predictable, and some criteria are likely to be improved in the future. For citrogypsum usage decision, the experts considered CP to be the most volatile criterion.

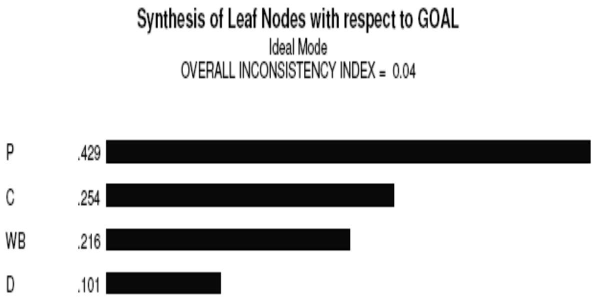

Figure 6(a). Synthesis of leaf nodes with respect to GOAL

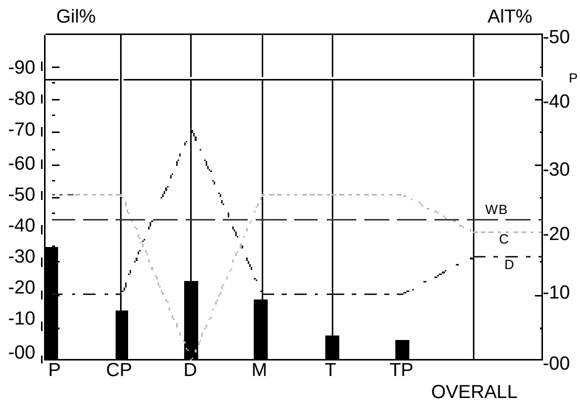

Figure 6(b). Performance sensitivity with respect to GOAL for nodes below GOAL

Figure 7(a) and (b) show the potential impact of the changes in CP on the priorities of the alternative sites. A 200% increase in the relative weight assigned to CP, from 13.8% to 27.6%, produced no change in the ranking of the sites in comparison to Figure 6(a) and (b). Individually and as a group, the experts explored the impact of numerous scenarios on the criterion weights and alternative priorities. They considered the solution presented in Figures 6(a) and 7(a) to be not only the most desirable, but also the most robust.

Determining the best usage cases for a citrogypsum is a problem that involves both quantitative and qualitative criteria. We used an AHP-Delphi multi-criteria model to elicit, process, and synthesize these quantitative and qualitative expert opinions. The proposed model uses Delphi technique to elicit expert opinions about criteria for evaluating the usage cases. Profitability, Capacity of Production, the Degree of investment, Marketable, Production ease and Time production were considered important by the experts. AHP and Expert Choice were used to capture the priorities of the individual decisions and to combine these individual assessments into a consensus. AHP was also used to compare the alternatives on the criteria, facilitate the calculations, and conduct sensitivity analysis.

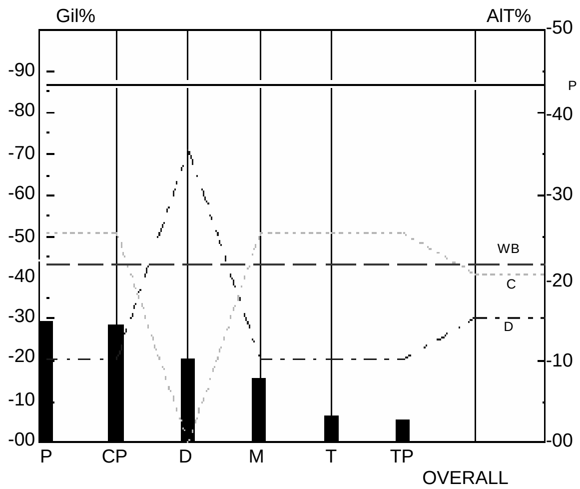

Figure 7(a). Performance sensitivity with respect to GOAL for nodes below GOAL

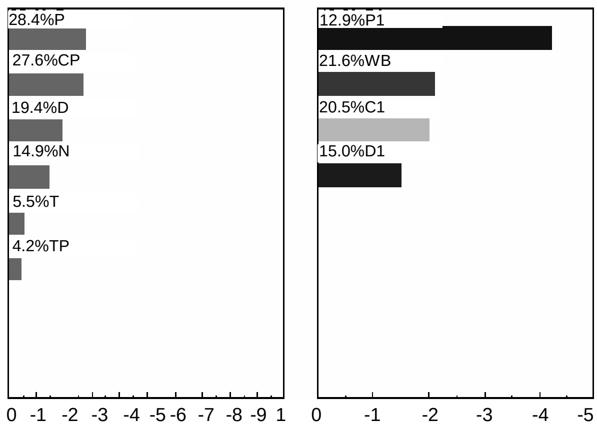

Figure 7(b). Dynamic sensitivity with respect to GOAL for nodes below GOAL

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