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# A Goal Programming Approach to Resource Allocation in Geothermal Energy Projects

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***Abstract**: The allocation of resources to competing project activities is a common challenge in project management. In this paper, a goal programming model was developed to determine the combination of time, labor and material resources along with the total amounts of resources required to undertake geothermal energy projects with special focus on exploration, production and operation stages of projects. Using goal programming, the objective is to minimize the objective function so that minimum resource requirements are utilized at the stages of projects. The sum of weighted deviations is minimized from the goal values and the projected completion times set for the geothermal energy projects. Resource leveling is achieved by using the simplex method for linear programming; that require solution of a minimization problem. Numerical examples are presented for illustration that determine the allocation of labor, material and time during exploration, production and operation stages of the projects. The solution provides feasible results; taking into account the contradictory nature of the criteria involved in executing geothermal energy project activities. The goal-based approach for resource allocation in geothermal energy projects is effective as a resource leveling tool for time, labor and material resources; where completion time and the relevant resource costs can be priortized if necessary.*

**Keywords—**Energy; goal; geothermal; modeling; resources; projects

## 1. INTRODUCTION

Resource allocation in project management decision frameworks has attracted interest has attracted interest from practitioners and academicians for a long time. Considering a Geothermal energy project framework, investment costs for setting up a plant requires cost effective methods of allocating resources (labor, material, time) in order to effectively execute activities during project exploration, production and operation. During the exploration stage, reservoir identification is crucial in order to study its possible use. Gathering and evaluation of existing data is crucial before core activities of surface exploration and exploration drilling take place. A prefeasibility report is vital before making an environmental assessment of the existing area. Drilling and testing of the confirmed wells are crucial; followed by a feasibility report.

Once the plant equipment is on order and plant construction under way, where at least 50% of the resource to be used for the power plant has been configured, production and injection drilling commence. When construction of the plant is finalized, start of operation of the geothermal plant is made whose main objective is aimed at optimizing production. This is achieved through appropriate designs, applying criteria for reservoir engineering and well production. The three stages enlisted demand optimal allocation of time, labor and material resources in order to sustain a cost-effective project management framework for geothermal energy generation.

## 2. LITERATURE REVIEW

Existing literature relating to the application of goal programming in project management is cited among several scholars. The goal programming technique originally developed in [1] allows taking into account simultaneously many objectives while the decision maker is seeking the best solution from among a set of feasible solutions. According to Aouni and Kettani [2] goal programming is an extension of linear programming for which effective solving algorithms are available. In [3[, Mukherjee and Bera examined the application of goal programming in project management; where project selection criteria were applied to Indian coal mining industry. The authors identify five major goals: capital investment goal, cost of production goal, profit goal, manpower goal and demand goal. According to Gyu and John [4], a goal programming model can be applied for project selection and resource planning. The authors used 0-1 integer programming model; which is validated by applying it to the case study from the Woodward Governor Company.In [5], Lee and Kim proposed an improved information system project selection methodology; which reflects interdependencies among evaluation, criteria and candidate projects by using network process with 0-1 goal programming. .Masood et al [6] developed a project selection model for health service institutions that incorporated research and development, investments plans, capital budgeting etc. The authors used 0-1 integer programming model which is validated by applying it to a real project selection data .Fabiane et al [7] applied goal programming to a Brazilian forest problem; seeking search to the following

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goals: wood harvest(pine),wood harvest(availability),tourism, employees, diversity of flora and diversity of fauna.Liang'8] focused on development of a two-phase mathematical programming approach for solving the multi-objective project management decision problems in a fuzzy environment. The model defined examined simultaneous total project costs, total completion time, and crashing costs with reference to direct costs, indirect costs, contractual penalty costs, duration of activities and the constraints of the available budget. In [9], a goal programming model was proposed by allocating time and cost in project management;whose approach is utilized in the proposed model for geothermal energy projects.

## 3.MODEL DEVELOPMENT

We consider a set of geothermal energy projects with a common goal of minimizing project resources (labor cost, material cost, completion tim

### *3.1Notation*

(i=1,2,……n) : Project stages for completion

(j=1,2,3) : Three distinctive phases of a given geothermal energy project to be successfully completed

(k=1,2,3): Goals to be achi(eved
Z : Value of objective function
$P_k(i)$ : Pre-emptive priority of the $k^{th}$ goal
$D^+_k$ : Overachievement of $k^{th}$ goal
$D^-_k$ : Underachievement of $k^{th}$ goal
$X_{ij}$ : Time allocated time for project i during phase j
$T_i$ : Total time of completion
$C_j$ : Monthly total costs(including miscellaneous costs)
$TC_i$ : Total cost(budget) of entire project
$A_j$ : Monthly labor and material costs
$LM_i$ : Total labor and material costs

### *3.2 Objective Function*

Consideration is given to pre-emptive priorities, over/under achievement of goals, yielding the following function:

$$\text{Minimize } Z = \Sigma^3_{k=1} \Sigma^3_{i=1} P_k(i)[D_k^+ + D_k] \quad (1)$$

### *3.3 Goal Constraints*

The geothermal energy projects are constrained in terms of time for completion, total cost(budget), labor and material costs.

*Total time of completion*

$$\Sigma^3_{j=1}\Sigma^i_{i=1} X_{ij} – D_1^+ + D_1^- = T_i \quad (2)$$

*Total Cost (Budget)*

$$\Sigma^3_{j=1}\Sigma^i_{i=1} C_i X_{ij} – D_2^+ + D_2 = TC_i \quad (3)$$

*Labor and material costs*

$$\Sigma^3_{j=1}\Sigma^i_{i=1} A_{ij} X_{ij} – D_3^+ + D_3^- = LMC_i \quad (4)$$

*Nonnegativity*

$$X_{ij} , A_{ij} , C_{ij} , D^+_1 , D^-_1 , D^+_2 , D^-_2 , D^+_3 , D^-_3 \geq 0$$

## 4. Goal Programming Model

We now formulate the goal programming model as follows:

$$\text{Minimize } Z = \Sigma^3_{k=1} \Sigma^3_{i=1} P_k(i)[D_k^+ + D_k^-]$$

Subject to:

$$\Sigma^3_{j=1} \Sigma^i_{i=1} X_{ij} – D_1^+ + D_1^- = T_i$$
$$\Sigma^3_{j=1} \Sigma^i_{i=1} C_{ij} X_{ij} – D_2^+ + D_2^- = TC_i$$
$$\Sigma^3_{j=1} \Sigma^i_{i=1} A_{ij} X_{ij} – D_3^+ + D_3^- = LMC_i$$

$$X_{ij} , A_{ij} , C_{ij} , D^+_1 , D^-_1 , D^+_2 , D^-_2 , D^+_3 , D^-_3 \geq 0$$

### *4.1 Solution Procedure*

The optimal solution in §4 is obtained following steps (i) to (iv) as follows:

(i) Start with the initial solution for which all decision variables are assumed to be at zero level
(ii) The objective function coefficients are pre-emptive functions; so $P_1(i)$ , $P_2(i)$ and $P_3(i)$ are placed in appropriate places of the initial tableau
(iii) All $D^+_k$ s must be considered at zero level, and hence only negative deviational variables $D^-_k$ s must appear in the basis of the initial Tableau
(iv) Use the simplex method to solve the minimization problem until optimality is achieved.

## 5.IMPLEMENTATION

### *5.1 Data Description*

In order to test the model presented. A hypothetical resource allocation problem for three geothermal energy projects is introduced in this section. We assume projects are to commence at the same time. The estimated monthly costs (in USD) of carrying out the projects are presented in Table 1. The total allocations (in USD) and project durations are presented in Table 2.

Project 1[i=1]

Table 1: Monthly Breakdown of Costs

| Project phase<br><br>(j) | Monthly Labor and material costs $LMC_i$ | Monthly total costs (including miscellaneous expenses) |
|---|---|---|
| PLANNING | | |

| | | |
|---|---|---|
| [Preliminary survey, exploration, test drilling, review] | 11,791.59 | 19,772.36 |
| EXECUTION [Development, production drilling, construction, start-up commissioning] | 37,340.02 | 626,124.71 |
| MONITORING [Operation, maintenance, control] | 7,861.58 | 13,181,57 |

Project 2[i=2]

Table 2: Monthly Breakdown of Costs

| Project phase (j) | Monthly Labour and material costs $LMC_i$ | Monthly total costs (including miscellaneous expenses) |
|---|---|---|
| PLANNING [Preliminary survey, exploration, test drilling, review] | 13,238.78 | 23,172.41 |
| EXECUTION [Development, production drilling, construction, start-up commissioning] | 419,228.09 | 733,792.97 |
| MONITORING [Operation, maintenance, control] | 8,825.85 | 15,449.27 |

Project 3[i=3]

Table 3: Monthly Breakdown of Costs

| Project phase (j) Monthly | Monthly Labour and material costs $LMC_i$ | Monthly total costs (including miscellaneous expenses) |
|---|---|---|
| PLANNING [Preliminary survey, exploration, test drilling, review] | 16,709.59 | 28,587.77 |
| EXECUTION [Development, production drilling, construction, start-up commissioning] | 52,753.94 | 905,279.50 |
| MONITORING [Operation, maintenance, control] | 11,139.73 | 19,058.52 |

Table 4

Total Allocations and Project Durations

| Project | Total labour and material costs (USD) | Total costs including miscellaneous expenses) (USD) | Duration (months) |
|---|---|---|---|
| 1 | 444,149.71 | 774,758.87 | 6 |
| 2 | 498660.78 | 872,827,43 | 8 |
| 3 | 629,394.48 | 1,076,806.14 | 11 |

The following priorities are desirable for each project:

Project 1:

$P_1(1)$: Complete project in 6 months

$P_2(1)$: Keep total project expenditure within budget (774,758.87 USD)

Project 2:

$P_1(2)$: Complete project in 8 months

$P_2(2)$: Keep total project expenditure within budget (872,827.43 USD)

Project 3:

$P_1(3)$: Complete project in 11 months

$P_2(3)$: Keep total project expenditure within budget (1,076,806.14 USD)

*5.2 Problem Formulation for Projects*

The problem seeks to allocate time for each phase of projects (planning, execution, monitoring) in order to achieve the time and total expenditure goals.

Project 1:

Minimize $Z = P_1(1)\, D^+_1 + P_1(1)\, D^-_1 + P_2(1)\, D^+_2 + P_2(1)\, D^-_2$

Subject to:

$X_{11} + X_{12} + X_{13} - D^+_1 + D^-_1 = 6$

$19772.36X_{11} + 626124.71\, X_{12} + 13181.57\, X_{13} – D^+_2 + D^-_2 = 774{,}758.87$

$11791.59X_{11} + 37340.02\, X_{12} + 7861.06X_{13} – D^+_3 + D^-_3 = 444{,}149.71$ $X_{11}\,, X_{12}\,, X_{13}\,, D^+_1\,, D^-_1\,, D^+_2\,, D^-_2\,, D^+_3\,, D^-_3 \geq 0$

Project 2:

Minimize $Z = P_1(2)\, D^+_1 + P_1(2)\, D^-_1 + P_2(1)\, D^+_2 + P_2(2)\, D^-_2$

Subject to:

$X_{21} + X_{22} + X_{23} - D^+_1 + D^-_1 = 8$

$23172.41X_{21} + 733792.97.X_{22} + 15448.27\, X_{23} – D^+_2 + D^-_2 = 872827.43$

$13238.78X_{21} + 419228.09\, X_{22} + 8825.85X_{23} – D^+_3 + D^-_3 = 498660.78$

$X_{21}\,, X_{22}\,, X_{23}\,, D^+_1\,, D^-_1\,, D^+_2\,, D^-_2\,, D^+_3\,, D^-_3 \geq 0$

Project 3:

Minimize $Z = P_1(3)\, D^+_1 + P_1(3)\, D^-_1 + P_2(3)\, D^+_2 + P_2(3)\, D^-_2$

Subject to:

$X_{31} + X_{32} + X_{33} - D^+_1 + D^-_1 = 11$

$28587.77X_{31} + 905279.5.X_{32} + 19058.52\, X_{33} – D^+_2 + D^-_2 = 1076806.14$

$16709.59X_{31} + 62753.94\, X_{32} + 11139.73X_{33} – D^+_3 + D^-_3 = 629394.48$

$X_{31}\,, X_{32}\,, X_{33}\,, D^+_1\,, D^-_1\,, D^+_2\,, D^-_2\,, D^+_3\,, D^-_3 \geq 0$

*5.3 Solution*

Using LINDO software, projects 1,2 and 3 models yield the following results:

Project 1:

$X_{11}$ = Time allocated for planning = 0 months
$X_{12}$ = Time allocated for execution = 1.09 months
$X_{13}$ = Time allocated for monitoring = 4.91 months

$P_1(1)$ : Goal for completing project 1 on time is fully achieved since $X_{11} + X_{12} + X_{13} = 6$ months but this solution is illogical and impractical because without planning phase, the project fails.

$P_2(1)$ : Goal for keeping total project expenditure within budgeted amount is partially achieved since
$19772.36X_{11} + 616124.71X_{12} + 13181.57X_{13}$
$= 19772.36(0) + 626124.71(1.09) + 13181.57(4.91)$
= 747,197.443 USD
Total projected labor and material expenditure
$= 11791.59X_{11} + 37340.02X_{12} + 7861.06X_{13}$
=11791.59(0) + 37340.02(1.09) + 7861,06(4.91)
= 79298.426 USD which is slightly above the budgeted amount of 774,758.87 USD

Project 2:

$X_{21}$ = Time allocated for planning = 0 months
$X_{22}$ = Time allocated for execution = 1.03 months
$X_{23}$ = Time allocated for monitoring = 6.96 months

$P_1(2)$ : Goal for completing project 2 on time is fully achieved since $X_{21} + X_{22} + X_{23} = 8$ months .However, this solution is illogical and impractical because without planning phase, the project fails.

$P_2(2)$ : Goal for keeping total project expenditure within budgeted amount is not fully achieved since
$23172.41X_{21} + 733792.97X_{22} + 15448.27X_{23}$
$= 23172.41(0) + 733792.97(1.04) + 15448.27(6.96)$
= 870,664.65 USD which is below the budgeted amount of 872,827.43 USD

Project 3:

$X_{31}$ = Time allocated for planning = 0 months
$X_{32}$ = Time allocated for execution = 1.03 months
$X_{33}$ = Time allocated for monitoring = 6.96 months

$P_1(3)$ : Goal for completing project 3 on time is fully achieved since $X_{31} + X_{32} + X_{33} = 11$ months, .but this solution is illogical and impractical because without the planning phase, the project fails.

$P_2(3)$ : Goal for keeping total project expenditure within budgeted amount is partially achieved since
$28587.77X_{31} + 905279.5X_{32} + 19058,52X_{33}$
= 28587.77(0) + 905279.5(0.98) + 19058.5210.02)
= 1,078,140.28USD . Total project expenditure = 1,078,140.28 USD which is slightly above the budgeted amount of 1,076,806.14 USD.

## 6.CONCLUSIONS

The goal programming model for resource allocation in geothermal energy projects was proposed. Results reveal that the model provide satisfactory levels of achievement for managing the three projects with pre-emptive goals. However, the solution value (0) of time allocated for planning is illogical and impractical, because without the planning phase, the project can fail. Additional research can aim at introducing additional constraints to the model, by specifying the lower bound for each time allocated to planning, execution and monitoring.

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