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A Metaheuristic for New Product Development

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Abstract. In this paper we consider employee assignment problem for a product development firm and develop a Tabu search algorithm for solving it. The Tabu search method iteratively allocates and deallocates employees to development projects, and accepts such a change if it leads to a new best solution. In addition, a not-as-good solution also has a chance of being accepted if it is not Tabu-ed, i.e., forbidden. We allows Tabu search to switch between intensification and diversification by controlling the acceptance probability. Computational study compares the Tabu search method with a hill climbing method, and the results show that that Tabu search significantly outperformed hill climbing

Keywords: Product development, Employee assignment, Heuristic, Metaheuristics, Tabu search, Optimization

1. Introduction

Innovation management has a broad range of applications and has been extensively studied in the literature (see [1]). For example, [6], [4] and [5] focused on new drug development in the biotechnology/pharmaceutical industry. In this paper, we consider new product development for a firm with multiple candidate products to facilitate the firm' s decision making on assigning employees to the product development teams. The firm has a forecast on the revenue of each project, as well as forecasts on the correlation of the revenues the products would bring. Furthermore, if the firm decides to develop a product, it incurs a fixed setup cost for that project. In real world scenarios, the firm has a limited number of employees to be utilized in order to maximize its risk-adjusted payoff. We solve the problem using Tabu search, which is a widely used metaheuristic method for combinatorial optimization problems [8] and has proven to be an effective strategy for optimization. A key concept in Tabu search is the use of a Tabu list, which stores recently visited solutions and prevents the algorithm from revisiting a recent solution by adding it to the Tabu list.

In the following sections, we will formulate the employee assignment problem with limited manpower. A hill climbing method is used to construct an assignment plan, and a metaheuristic method is developed to improve the solution quality. We will present computational results, and conclude the paper with potential future work.

2. Problem Formulation

We assume that each development project has a fixed setup cost, and that the the expected revenue of the project is $a_i x_i$ if xi employees are assigned to project *i*. For example, by spending more effort on the project we can speed up its development and thus realize its gain more quickly, which would lead to a larger net present value (NPV). Furthermore, the revenues of the projects are correlated. For example, the actual realized revenues of the projects could be affected by macro-economic variables such as GDP and interest

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rate. In addition, the R&D firm has limited manpower, and thus may not able to assign as much manpower as needed to each project. We assume that the firm pays no extra cost to assign its employees to the projects since the employees' salaries are considered as sunk cost for the firm. However, the supply of the manpower is not unlimited, and is capped above by C.

In the following, let N be the number of projects and s_{ij} denote the covariance of the unit revenues for project i and j. k_i denotes the fixed setup cost for project i. Then, the firm maximizes its risk-adjusted utility function, f(x), as follows.

$$\max_{x_1,\ldots,x_N} \sum_{i=1}^{N} a_i x_i - r \sum_{i=1}^{N}\sum_{j=1}^{N} x_i x_j s_{ij} - \sum_{i=1}^{N} k_i 1\{x_i \neq 0\}$$

$$\text{s.t.} \quad \sum_{i=1}^{N} a_i x_i \leq C \qquad (!)$$

$$x_i \geq 0 \text{ for } i = 1, \ldots, N \qquad (2)$$

$$x_i \text{ is an integer for } i = 1, \ldots, N, \qquad (3)$$

where 1{ • } is the indicator function and r is the risk-adjustment coefficient. Constraint (1) limits the amount of manpower the firm can utilize.

The problem is clearly NP-hard, since the quadratic knapsack problem [10] is a special case of the model presented above. To solve the problem, we will first construct a solution using a hill-climbing based approach. Tabu search is then developed to improve the solution quality.

3 Construction Method

Constructing a good solution for the employee assignment problem with correlated revenues is not a simple task due to the correlation between the revenues. For instance, the well-known dynamic programming approach for knapsack problems [9] does not work here, due to lack of sub-problem optimality (i.e. Bellman ' s principle of optimality [2]). Instead, we develop and implement a hill-climbing based construction method as follows.

We start with the naive solution x = (0; : : : ; 0), that is, the firm doesn't carry out any project. We then iteratively improve the solution quality by changing x_i by i, with _i ∈ {−1; 1}; we call this operator 1-Opt. That is, we increase or decease the number of employees working for project i by one. More specifically, in each iteration we go through i ∈ {1; : : : ;N} and check whether changing xi to xi+_i will improve current solution or not. If it does, we modify current solution by setting xi = xi + _i, and repeat the process. We stop until no further improvement can be made. To search a larger neighborhood, we also implement a variant of the construction method with 2-Opt that allows simultaneously changing xi and xj by _i and _j respectively, where i / = j and _i; _j ∈ {−2;−1; 1; 2}. In each iteration of this construction method, we modify the allocated manpower of two projects aiming to improve the risk-adjusted utility for the firm while maintaining the feasibility of the solution. Again, we repeat the step until there is no further improvement.

4 Tabu Search

Tabu search [8] is a metaheuristic that is an extension to Hill-climbing algorithm combined with a so-called Tabu list. The Tabu list consists of recently visited solutions. When deciding whether to accept a candidate neighboring solution or not, the algorithm checks if the candidate solution is in the Tabu list. If it is in the Tabu list and does not satisfy an aspiration criterion, the solution is rejected. The use of a Tabu list will likely prevent the algorithm from repeatedly visiting a small set of solutions, and thus promote diversification (see [3] and [7] for more on Tabu search and its applications to optimization problems). Our implementation of Tabu search for employee assignment optimization is given in Algorithm 1.

In our computational experiment, the initial solution is either x = (0; : : : ; 0) or the solution produced by the construction heuristic, and the initial diversification probability is set as P =0:5. The new diversification probability is calculated by the formula $P' = \lambda P$, where P is the new probability and λ = 0:99 is the decay rate. In each step, we examine M = 40 best neighbors, and the Tabu list is of length 7. The stop criterion in Algorithm 1 is to stop the iterations if we see no improvement of the best solution for NI cycles, and NI is set at 300.

5 Computational Results

We implemented the construction method and Tabu search algorithm in Java, and tested the methods with 100 randomly generated problem instances with N = 100 projects. The results in Table 1 show that with 1-Opt only Tabu search produces much better solutions than the construction heuristic. The average improvement is about 77.92%, at the cost of more computation time (however, on average the Tabu search method took less than 0.1 seconds on a Intel Core2Duo computer with two 2.26GHz CPUs and 2G RAM). Lastly, when both 1-Opt and 2-Opt were used the gain of Tabu search decreased to 2.17%, which demonstrated the power of a larger neighborhood move for the construction heuristic.

Algorithm 1 Tabu Search for Employee Assignment Optimization
Get an initial solution *xcurrent* and an initial diversification probability *P*.
Set *xbest* = *xcurrent*.
while Stop criterion not satisfied **do**
Select a set of *M* best neighbors of *xcurrent* by 1-Opt or 2-Opt ordered by decreasing utility
for each selected neighbor *x* **do**
Let $\Delta = f(x) - f(xcurrent)$.
if $f(x) > f(xbest)$ or $\Delta \geq 0$ **then**
Set *xcurrent* = *x*.
if $f(x) > f(xbest)$ **then**
Set *xbest* = *x*.
end if
break
else
if *x* is not on the Tabu list and random uniform(0,1) $\leq 1 - P$ **then**
Set *xcurrent* = *x*.
Update the Tabu list with *x*.
break
end if
end if
end for
Reduce diversification probability *P*.
end while

Table 1: Statistics of Solutions by Construction Heuristic and Tabu Search with 1-Opt

	mean	standard deviation ratio	signal to noise
Construction	7018.88	1306.15	5.37
Tabu	12488.06	2225.83	5.61

6 Conclusions and Future Work

We have formulated the employment assignment optimization problem and solved it using construction heuristic and Tabu search, and the computational results demonstrated that Tabu search produced better results. For future work, we will explore the problems with variable cost for assigning employees to a project;

another possible extension is to consider employee skill types, and only allows employees with matched skills to work on projects that require those skills. In addition, other popular metaheuristic methods, such as simulated annealing and Genetic Algorithm, may produce solutions of better quality. Lastly, neighborhood moves that involve more than two projects are worth exploring as well.

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