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Decision-Making Optimization of TMT: A Simulated Annealing Algorithm Analysis

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ABSTRACT

The decision-making of Top management team (TMT) has been a hot point in academic. The paper find out annealing algorithm method can effectively solve the decision-making optimization problem. Through considering the quality and efficiency of decision-making, applying the annealing algorithm, the optimal decision preference sequence is found. Finally, an application case is proposed. Through determining the initial solution, and choosing the solution neighborhood, and setting the cooling function and temperature, with the simulated annealing algorithm, the optimal solution of the decision is achieved.

Keywords: *Top Management Team, Simulated Annealing Algorithm, Decision-Making*

1. Introduction

Upper Echelons Theory is the theory which has profound impact in the academic circles. It is proposed in 1984 by Hambrick and Mason who suggested that researching into top management team (TMT) decision-making instead of individual decision-making would decrease the decision fault caused by the individual of limited rationality [1]. As a result, problems about decision-making of TMT become popular and stimulate a lot of research. Most part of the research has focused on TMT demographic characteristics and their heterogeneity. The researchers suggested that the demographic characteristics and their heterogeneity could reflect the decision-making of TMT and predict organization outcome. There is advantages in this static analysis which can evaluate and predict performance of a company to some degree, however, the demographic characteristics are not the exact reflection of TMT decision-making [2], and cannot answer the question of decision-making optimization of TMT. In this case, we propose two dimension which is decision efficiency and decision quality to analyze decision-making optimization of TMT and find out the optimal decision preference sequence.

2. Literature Review

In the violent changing society, decision effect is directly influenced by decision efficiency. Ensley (2000) suggested that decision efficiency and cohesion are two core factors influencing team performance [3]. In fact, team cohesion is a kind of condition and display of decision-making quality. To improve the decision-making quality is one of the key factors which prompt the top management research changing from individual level to team level. Decision-making quality of TMT has important influence on decision-making effect despite of the changing environment. Therefore, the decision-making effect depends on decision-making efficiency and decision-making quality. Higher level of decision-making efficiency and decision-making quality will result in better decision-making effect.

2.1. Measurement of Decision-Making Efficiency

How can we achieve high decision-making performance? Economist Heyek once pointed out that decision-making efficiency depended on the matching degree of decision-making power and key decision knowledge [4]. He suggested to combine the power and the knowledge. Only combining the two can it achieve high efficient decision-making. However, Heyek's saying is too obscure that he didn't point out how power and knowledge combined. In fact, decision-making efficiency can be measured by the weighted preference of all the alternative choices from all decision-makers, that is to say, base on the consideration of all decision-makers' decision-making preference, comprehensively consider the "preference distance" be tween the final and the original preference sequence of decision-making which is the difference of the two. If the "preference distance" between the two is bigger, the efficiency will be lower.

2.2. Decision-Making Quality

To improve decision-making quality of individual executives is the primary idea of introducing the theory of TMT [1]. Although the substitution of group rationality for individual rationality can't completely eliminate the negative influence of limited rationality in improving decision quality, it can validly reduce the bounded rationality in decision-making which comes from the interactions between team members [5]. However, interaction is only the necessary condition in improving decision-making not the sufficient condition, so the decision quality evaluation should be done by other factors. Reviewing the related past research on quality of decision-making, the decision-making quality evaluation is mainly done by the subject idea of the TMT members which mainly using psychological scale to investigate TMT's opinion to every decision-making quality, such as Wang Guofeng [6]. The inner logic lies in the feasibility of decision-making quality evaluated by satisfaction degree of TMT. This rooted in the posterior characteristic which TMT decision-making quality should be evaluated by the objective decision implementing effect, however, in the real setting, it is not feasible. One reason is that it will take quite a long time to see the actual effect, when the time past, the uncontrollable factors influenced decision will increase. So, the ineffective of decision can not attribute to the bad quality of decision-making; another reason is that it won't be good for the improving of decision process if the decision-making factor be evaluated by the decision implementing effect. Therefore, this paper uses the satisfaction of top management team with the decision-making process to evaluate the decision-making quality. When the degree of TMT members' satisfaction in decision-making with the decision-making quality is higher, the decision-making quality is higher.

3. Optimization Model of TMT Cognitive Integration

Based on above findings, the optimization model of top management team cognition integration is built. Suppose in every decision process, TMT faces a decision-making program set, set it as A = $\{a_j\}$, j = 1, 2, …, n, TMT members set K = $\{k_i\}$, I = 1, 2, …, m. First, TMT members form preference sequence of the program set A based on their own information sources, set the sequence as X = $\{x_{ij}\}$. The principles of optimization of cognitive integration are high decision making efficiency and high quality.

3.1. High Efficiency of Decision-Making

Based on the consideration of the weight of every decision-maker, when the "preference distance" between final and original preference sequence of TMT decision-making is smaller, the efficiency of decision-making will be higher. For the "preference distance" measurement, some scholars (such as Zhang Lin *et al*, 2004) proposed to use the Mahalanobis distance [7]. However, in fact, compared to the Euclidean distance, Mahalanobis distance gets its advantages in the correlated sample. In this study, the primary preference based on their own discretion rather than on the idea of intercommunication. It depends more on the inter independence rather than the inter correlation. So, it is more easy and effective to use Euclidean distance than Mahalanobis distance. As it is known that Euclidean distance $d_E(x, y)$ between two point (or vectors) x, y is:

$$d_E(x,y)=\sqrt{\sum(x-y)^2} \tag{1}$$

To simplify the calculations, the "preference distance" will take the square of Euclidean distance, which is "preference distance" d_i:

$$d_i=\sum_{j=1}^{n}(x_{ij}-e_j)^2 \tag{2}$$

The shorter of Euclidean distance means the higher of decision-making efficiency. Considering different weights W_i of each decision-maker in decision-making, the following model can be established to represent the decision-making efficiency optimization:

$$\begin{cases} \min E(x)=\sum\limits_{i=1}^{m} w_i d_i=\sum\limits_{i=1}^{m} w_i \sum\limits_{j=1}^{n}(x_{ij}-e_j)^2 \\ s.t. \sum\limits_{i=1}^{m} w_i=1, 0<e_j<1, 0<x_{ij}<1, w_i>0 \end{cases} \tag{3}$$

3.2. High Quality of Decision-Making

The quality of decision-making can be measured by TMT members' satisfaction degree with the decision quality. Zhang Lin *et al* [7] proposed the concept of using relative entropy to measure the quality satisfaction with decision-making. The so-called relative entropy is an important concept in information theory which measures the fitness degree of two messages. As to variable X, Y, when $X = (x_1,\ldots\ldots x_n)$; $Y = (y_1,\ldots\ldots y_n)$, $0 \le x_n \le 1$, $0 \le y_n \le 1$, and $\sum_{i=1}^{n} x_i=\sum_{i=1}^{n} y_i=1$, the relative entropy of X compared to Y is $h(x,y)=\sum_{i=1}^{n} x_i \ln\frac{x_i}{y_i}\ge 0$. Obviously, $\forall i$, if and only if $x_i = y_i$, $h(x,y)$ get its minimum. In reverse, the lower of $h(x,y)$, the more closer between

x_i and y_i, So $h(x,y)$ can be use to measure the fitness degree between x_i and y_i.

When the fitness between final optimal solution sets decided by TMT after discussion and the preference sequence of every TMT is higher, the overall satisfaction is higher thus with the decision-making higher as well. So the decision-making quality of TMT can be measured by q_i:

$$q_i = \sum_{j=1}^{n} x_{ij} \ln \frac{x_{ij}}{e_j} \tag{4}$$

Considering different weight W_i of every TMT member in decision-making, a model can be established to simulate the optimization of decision-making quality:

$$\begin{cases} \min Q(x) = \sum\limits_{i=1}^{m} w_i q_i = \sum\limits_{i=1}^{m} w_i \sum\limits_{j=1}^{n} x_{ij} \ln \dfrac{x_{ij}}{e_j} \\ s.t. \sum\limits_{i=1}^{m} w_i = 1, 0 < e_j < 1, 0 < x_{ij} < 1, w_i > 0 \end{cases} \tag{5}$$

Integration of the various members of TMT preference was based on the consideration of both decision-making quality and decision-making efficiency, that is either to find the fittest preference set to ensure the decision-making efficiency or make every TMT member satisfy to ensure the decision-making satisfaction. So, the optimization model of TMT decision-making process can be express by following equation set:

$$\begin{cases} \min decision = \alpha E(e_j) + \beta Q(e_j) \\ \quad = \sum\limits_{i=1}^{m} w_i \left(\alpha \sum\limits_{j=1}^{n} (x_{ij} - e_j)^2 + \beta \sum\limits_{j=1}^{n} x_{ij} \ln \dfrac{x_{ij}}{e_j} \right) \\ s.t. \ \alpha + \beta = 1, \alpha > 0, \beta > 0, \\ \quad 0 < e_j < 1, 0 < x_{ij} < 1, \\ \quad \sum\limits_{i=1}^{m} w_i = 1, w_i > 0 \end{cases} \tag{6}$$

In Equation (6), $decision$ is the dependent variable of object function, α, β are the weight factors of decision-making efficiency and decision-making quality, represent the importance of efficiency and quality of TMT decision-making. When the value of α is bigger representing that TMT laid more emphasis on decision-making efficiency; when the value of β is bigger representing that TMT laid more emphasis on decision-making quality. The object of TMT cognition integration optimization is to find out the optimize preference sequence set $E(e_j)$. As can be seen from the equation set, this problem is a NP-hard problem, and is a kind of continue optimization problem which is hard to get overall optimal solution by ordinary methods. Even if the optimal solution can be achieved, the solution efficiency is low enough. So, we use the Simulated Annealing (SA) Algorithm to solve the problem.

4. Problem Solving

Simulated annealing algorithm (Simulated Annealing Algorithm, SA algorithm) is inspired by the phenomenon of annealing process in thermodynamics which will achieve equilibrium ultimately. SA can search for the optimal solution simulating the annealing process. The algorithm can achieve an approximate global optimal solution in polynomial time through the selection of relatively small state in target areas in certain probability [8]. In this paper, the reason to use SA is as follows.

1) SA likewise intelligent optimization algorithms is "problem dependent", and its research focus is on the application of algorithm in various complex problems [8]. However, in the research of TMT, seldom application researches of SA can be seen.

2) Compared to genetic algorithms and other intelligent optimization algorithm, SA is more effective in finding the global optimal solution as it accept second-best solution in certain probability through the rules of Metropolis which greatly enhance the capacity of global searching.

The solving step of this problem can follow several steps:

Step 1: Each TMT member has their own preference to the program set, to put them all we can get the initial preference sequence of TMT , randomly choose an initial solution $E^i = \{e_1^i, \ldots\ldots, e_n^i\}, 0 \le e_l^i \le 1$, $l = 1, 2, \ldots, n$. Given initial temperature T_0 and ending temperature T_f, let iteration index $k = 0$, $T_k = T_0$.

Step 2: In the neighborhood of initial solution, randomly generate a neighbor solution $E^j = \{e_1^j, \ldots\ldots, e_n^j\}$, $0 \le e_l^j \le 1$, $l = 1, 2\ldots, n$, calculate the incremental value of the objective function:

$$\Delta decision = decision(e_l^j) - decision(e_l^i) \tag{7}$$

Step 3: If $\Delta decision < 0$, let $i = j$ and go to step 4; otherwise, generate $\xi = U(0,1)$, if $\exp\left(-\dfrac{\Delta decision}{T_k}\right) > \xi$, let $E^i = E^j$.

Step 4: If the thermal equilibrium (*i.e.* frequency of inner cycle become greater than the frequency of setting cycle $n(T_k)$), then go to step 5; otherwise go to step 2.

Step 5: According to $T_{k+1} = r \cdot T_k$ lower the temperature, (r generally values from 0.95 to 0.99 with two decimal places, otherwise the cooling rate either too fast or too slow), $k = k + 1$, if $T_k < T_f$ the algorithm stops, otherwise go to step 2.

5. Application Examples

A TMT of one firm with five members which one is CEO while the others are vice presidents in charge of each functional department. In one decision-making conference, there are 6 decision programs for discussion and decision. Before the decision debate, the preference sequences to the decision program of every TMT member are listed in **Table 1**.

Suppose the decision weight of CEO is 0.4, each vice president is 0.15, the weight factor α, β of decision-making quality and decision-making efficiency are both 0.5. That is, the decision-making quality and efficiency are the same important.

5.1. According to the Problem Characteristics to Determine the Initial Solution

If randomly generate an initial solution, high temperature annealing process would be relatively long. CEO noted that the weight is high, the initial solution can be shilling for the CEO's preference sequence, that is, $\mathbf{E}^0$ = (0.5, 0.4, 0.8, 0.3, 0.1, 0.3). Considering the decision weight of CEO is the highest, we can choose the CEO's preference sequence as initial solution, that is, E^0 = (0.5, 0.4, 0.8, 0.3, 0.1, 0.3).

5.2. The Choice of Neighborhood

The choice of neighborhood plays a very important role in problem solving efficiency, but the choice methods closely linked to specific issue. Because the solution of this problem is in the (0,1) interval, and the computer will treat the solution closed to 0 as 0 as limited by the computer precision, the program running would occur error as the calculation has exceeded the definition domain. So, it is not suitable to have a random search around the neighborhood of the previous solution. In order to ensure not only the solution is in the definition domain, but also ensure a relatively wide search range, we carried out the following neighborhood search method as follows to determine the new solutions: First, code the preference sequences exactly from the original sequence, such as (0.5, 0.4, 0.8, 0.3, 0.1, 0.3), then swap the preference value in the sequence itself. As the size of neighborhood is c_6^2 = 15, so the number of inner loop is 15 times.

Table 1. Initial decision preference order of TMT.

TMT \ program	1	2	3	4	5	6
CEO	0.5	0.4	0.8	0.3	0.1	0.3
VP1	0.4	0.5	0.7	0.8	0.2	0.5
VP2	0.7	0.2	0.3	0.7	0.2	0.4
VP3	0.6	0.7	0.2	0.6	0.4	0.5
VP4	0.6	0.6	0.1	0.5	0.8	0.1

5.3. The Choice of Cooling Function

There are many setting of cooling function. According to the characteristics of this problem, we use moderate cooling rate, the cooling function is defined as $T_{k+1} = r \cdot T_k$, r equals 0.97, that is $T_{k+1} = 0.97 \cdot T_k$.

5.4. The Initial Temperature and the to be Determined Temperature

According to the scale of this problem, the initial temperature T_0 equals 50, final temperature T_f equals 0.1.

5.5. The Retention of Good Solution

Although in theory, the probability of a simulated annealing algorithm will converge to global optimal solution at a probability of 1, but it is far from the reality [9], it is greatly related to the actual problem solving. In this study, as neighborhood search is random exchange within the old solution, the search process is random, so the global optimal solution may appear in the iterative process but the end. As a result, in order to prevent missing out the optimal solution, all solutions must be retained per iteration, and then filter them where the optimal solution can be determined.

5.6. Results

According to the above algorithm and parameter setting step, using VB language for programming, after 20 times iteration, removing repetitive solution, obtain the following results shown in **Table 2**:

As the minimum function value is 0.0942 is, so respectively (0.4, 0.5, 0.3, 0.3, 0.8, 0.1) is the optimal TMT decision-making preference sequence, and thus program 5 with the weight 0.8 is the optimal program. This is the solution under 20 iterations calculation. According to SA algorithm, this solution is the global optimal solution of this problem.

Obviously, optimal solution (0.4, 0.5, 0.3, 0.3, 0.8, 0.1) is quit different from the mean value of preference sequence (0.56, 0.48, 0.42, 0.58, 0.34, 0.36) which represent that it would not achieve high efficient and high quality decision-making through simple averaging. This may attribute to the mean value which represents a "compromise" program, and this simple "compromise" approach may put the choice of the program into two problem: on one hand, it can not take into account the interests and preferences of all decision-maker which a simple "compromise" program can not be accepted by everyone very quickly; on the other hand, the "compromise" preference program is different from most member's preference which more or less make TMT members

Table 2. Calculation result.

Iteration \ Program	1	2	3	4	5	6	Function value
1	0.8	0.3	0.1	0.3	0.5	0.4	0.1666
2	0.4	0.5	0.3	0.3	0.8	0.1	0.0942*
3	0.3	0.4	0.1	0.3	0.8	0.5	0.1626
4	0.1	0.4	0.3	0.3	0.5	0.8	0.3661
5	0.8	0.4	0.3	0.5	0.1	0.3	0.3299
6	0.8	0.1	0.3	0.3	0.5	0.4	0.279
7	0.3	0.3	0.1	0.8	0.5	0.4	0.1481
8	0.5	0.3	0.4	0.3	0.8	0.1	0.1308
9	0.4	0.8	0.1	0.3	0.3	0.5	0.222
10	0.3	0.3	0.1	0.5	0.8	0.4	0.1481
11	0.4	0.1	0.3	0.5	0.3	0.8	0.4071
12	0.3	0.5	0.1	0.8	0.4	0.3	0.174
13	0.1	0.8	0.3	0.5	0.4	0.3	0.2703
14	0.3	0.4	0.1	0.5	0.8	0.3	0.1131
15	0.3	0.1	0.4	0.3	0.5	0.8	0.4027
16	0.5	0.3	0.1	0.4	0.8	0.3	0.1068
17	0.3	0.3	0.1	0.4	0.8	0.5	0.1699
18	0.5	0.3	0.1	0.3	0.4	0.6	0.2664
19	0.3	0.1	0.3	0.4	0.8	0.5	0.2823
20	0.8	0.5	0.4	0.3	0.3	0.1	0.1902

unsatisfied which result in overall deny of this program. Therefore, a simple compromise decisions is inappropriate. It should take into account the preferences of all decision-makers with in-depth exchanges and discussions and the consideration of decision-making efficiency and all parties' satisfaction, thus comes out the optimal decision.

6. Conclusions and Discussions

This study found that:

First, taking into account both the quality of decision-making and efficiency of decision-making, the TMT, the average decision-making preference sequence is not the optimal sequence. TMT decision-making therefore can not simply choose the mean preferences of all team members. When choosing decision-making program with "mean highest" method should also taken the quality and efficiency of decision-making factors into account, using more advanced algorithms such as simulated annealing algorithm to find out the optimal decision sequence.

Second, simulated annealing algorithm can successfully solve the optimization problem of TMT decision-making, and it is an effective tool in complex issues in TMT decision-making optimization.

The shortcomings of this study are:

First, this study only intercept two variable—the quality and efficiency of decision-making—to search for the optimal sequence of cognitive preferences, we need further investigation to find out whether there are better variables. At the same time, the usage of Euclidean distance and relative entropy to measure these two variables has not been empirical investigated but only two hypotheses based on theoretical derivations.

Second, this study did not take limited rationality into account. In fact, although the group is relatively rational than individual, it is difficult to avoid the rational bias, especially when group thinking exist [10]. Although the satisfaction degree of team member is high, the quality of the overall decision-making from external perspective may not so high. How to reduce the group's limited rationality and to improve group performance is worth studying.

Third, the application of simulated annealing algorithm will be quite different as the problem changed. So the application techniques play an important role. In this study, the using of inter-switch method in neighborhood searching greatly improve the calculation efficiency but discretize the search of new solution which makes some potential solutions cannot be searched which eliminate the advantage of stimulate annealing algorithm. This problem still needs to further investigate to find out better neighborhood search method.

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