The Simulated Annealing Algorithm and Its Application on Resource-saving Society Construction

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***Abstract*—Construct the resource-saving society, which not only help to implement the scientific development concept, change the economic growth mode, but also contribute to implement the sustainable development strategy. Evaluation index system construction is part and parcel of building a resource-saving society; a scientific and rational evaluation index system not only can evaluate the resource-saving society construction standard, but also can guide the resource-saving society construction. Based on the analysis of the resource-saving society evaluation status quo, this paper established an evaluation index system including economic, social, environmental and technological, described the optimization ideas, algorithms and implementation of Simulated Annealing(SA). In this paper, the Hebei region as a case, which verified the SA results accuracy compared to the traditional BP network algorithm, and applied to North China, Central China and Northeast China, including 11 provinces and municipalities, the results showed that in line with the actual situation and have certain guiding significance, and the model's commonality is very good.**

***Index Terms*—SA, resource, save, saving-society, sustainable**

I. Introduction

The general resource is that all the necessary material and non-material elements of the human survival, development and enjoyment, so the resources not only include natural objects of the human need, such as sunlight, air, water, mineral, soil, plants and animals, etc. , but also include all useful objects of the human labor products form, such as various housing, equipment, other consumer goods and capital goods, also include intangible assets, such as information, knowledge, technology, the human physical power and Intelligence. Resource is narrowly defined as natural resources. In July 1993 the first edition of "the latest English-Chinese Dictionary", the concept of save is explained comprehensively, which is the economy, cut expenditure, savings, control, cost savings and live frugally; the antonyms is waste and extravagance. The object of save is human, financial, material and time; the main body of save is the organizations and individuals who use human, financial, material and time resources. Resource-saving society is that scientific development ideas as a guide, the save logos impenetrate in various fields, including production, circulation, consumer and social life, through the adoption of legal, economic, administrative and other comprehensive measures, rely on scientific and technological progress, mobilize and encourage the whole society to use resources rationally, maximize conservation resources, improve the resource use efficiency, with minimal resources consumption and environmental costs, access to the greatest possible economic and social benefits, and realize ultimately the coordinated development including resources, environmental, economic and social.

The importance of constructing resource-saving society has been approved at home and abroad, but to what extent, it is considered a resource-saving society, and what indicators to measure, there are also no uniform standard at home and abroad. Resource-saving society evaluation is to quantify the resource use efficiency and saving degree of a region. In the course of the quantified study, because the specific regions have the different actual conditions, the socio-economic develop incessantly, the science and technology is in constant progress, in conditions of limited resources, if have not a clear evaluation index system as measuring standards, then it would be difficult that realize the resource-saving society higher level transformation, which from the idea level to the operational management mode in practical work; at present, available quantified methods include mainly

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principal component analysis, factor analysis, AHP, entropy Law, etc. In this paper, the innovation lies in building comprehensive index system including the four aspects, such as economic, social, environmental and technological, applying Simulated Annealing Algorithm (SA) to quantitative analysis, and putting forward a new train of thought and method on how to build a resource-saving society.

II. THE SA PRINCIPLE

Annealing is a process that solid metal will be heated to the temperature above the melting point, and then cooling down gradually. In this process, because of heating, the metal elements in the active state will be in the whole minimum energy state finally, thus generate single crystal provided with regular structure, and the rapid cooling will lead to the crystal structure irregular or other defects. SA is an optimization method which simulates the physical process by the course of seeking the function minimum value.

A. The combined optimization ideas of SA

$S = | S_1, S_2, \ldots, S_N |$ is a collection by the formation of the possible combination or state, S is the solution space, S_i is the state (that is feasible solution), f: S→R is the goal or the cost function, $f(S_i) \geq 0$ reflects the cost which takes the state S_i as the solution, and then the combined optimization problem can be expressed as: seeking $S^* \in S$, to meet

$$f(S^*) = \min f(S) \qquad \forall S_i \in S \tag{1}$$

The combined optimization ideas of SA as the following:

We take each combination state S_i as a micro-state of the substance system; take $f(S_i)$ as the internal energy of substance system in the state of S_i, and take the control parameter T as the thermodynamic temperature. Let T decrease slowly from an enough high value, for each T, use Meropolis sampling algorithm to simulate the system's heat balance under this T by computer, that is the current state S give birth to a new state S ' through random stirring. Calculate the incremental digital $\triangle f = f(S') - f(S)$, and take the probability $\exp(-\triangle f / T)$ accepting S' as a new current state. When the random stir repeat enough so number, the probability of the state S_i as the current state will be subject to the Boltzmann distribution.

B. The two algorithms of SA

SA includes Meropolis sampling algorithm (M algorithm) and Annealing Procedure (AP) algorithm.

(1) Use AP algorithm to simulate the annealing process of solid material cooling, and use the cooling schedule to regulate T; for $\forall T$, regulate M algorithm, and carry through iterative calculations, until meet to the termination conditions.

(2) Use M algorithm to simulate the heat balance process in the state of T, take S_i as the initial state and then generate new solutions S_j by the new solution generator (Random stirred algorithm).

$$S_j = S_i + \Delta S$$

$$\Delta f = f(S_j) - f(S_i)$$

According to the accepted criteria, decide whether to accept the new solution S_j, until meet to the heat balance.

In this paper, SA algorithms summarized as follows:

1) AP algorithm

Step 1: Given S_0, suppose the initial current solution S (0) = S_0, set a higher initial temperature $T_0 > 0$, the iteration number i= 0, the test accuracy ε;

Step 2: Order $T=T_i$, take T and S (i) as the parameters, regulate M algorithm and take the return state of M algorithm as the current state, S (i) = S;

Step 3: Use the cooling schedule ($T_{i+1}=\alpha T_i$) to cooling, $T=T_{i+1}$, $T_{i+1} < T_i$, i=i+1;

Among them, α value is in between 0.8 to 0.9999.

Step 4: Test the AP whether to meet the termination conditions, if meet, to Step 5, otherwise, to Step 2;

Step 5: Take the current solution as the optimal output solution, S*= S (i), stop.

2) M algorithm

Step 1: Order k=0, S (0) = S, carry out the following steps in the state of T;

Step 2: Use a new solution generator S'= S (k) + σe to generate new solution S', and then calculate

$$\Delta f = f(S') - f[S(k)]$$

In the formula, e is random stirred and subject to Cauchy distribution; σ is the step value related the initial value and the value range.

Step 3:

① If $\triangle f < 0$, then S (k +1) = S'

② If $\triangle f \geq 0$, then calculate the receiving probability r

$$r = \exp\left[\frac{-f(S')}{T}\right]$$

$$if \quad r > pp \quad then \quad S(k+1) = S'$$

$$else \quad S(k+1) = S(k)$$

Among them, pp = random (0, 1) is the random function of uniform distribution in the interval [0, 1].

Step 4: k=k+1, if the algorithm meets the termination conditions, then go to Step 5, otherwise, to Step 2.

Step 5: the current solution S (k +1) return to AP algorithm.

3) The achievement of SA combined optimization algorithm

SA algorithm is similar to M algorithm, which also starts from an initial solution, after a lot of the transformation; we can obtain the relative optimal solution of the combined optimization problem at a given control parameters. Then reduce the control parameters T value, repeat the M algorithm, and then obtain the overall optimal solution of the combined optimization problem when the control parameters T are near 0. Only the solid annealing cooling down slowly, the solid can reach heat balance in each temperature and then tend to the groundstate of the energy minimum ultimately; so only the control parameter value also decay slowly, which can ensure SA algorithm tend to the overall optimal Solution of the combined optimization problem ultimately. In each T_i, a new state S(k+1) depends on a previous state S(k) totally, which may has nothing to do with the previous state S(0), S(1),…, S(k-1), so this is a Markov process.

SA algorithm generates the solution's sequence of the combined optimization problem using M algorithm, and then according to corresponding frequency p_i with the corresponding M rule, determine whether to accept the transfer from the current solution i to the new solution j.

$$p_i(i \Rightarrow j) = \begin{cases} 1, & f(j) \le f(i) \\ \exp\left(\dfrac{f(i)-f(j)}{T}\right), & f(j) > f(i) \end{cases} \quad (2)$$

In the formula, T∈R* show the control parameters. At the beginning, we give T a higher value, which corresponding to the solid solution temperature, in sufficient number of transfer, decrease T value slowly, which corresponding to cooling down slowly, so repeat until meet a cease criteria, the algorithm stop finally. Therefore, SA algorithm can be seen as M algorithm iteration while diminishing the control parameters value.

SA algorithm accepts the new solutions based on M criteria, therefore, in addition to accept the optimal solution, still accept the deterioration solution within a limit range, which is the essential difference between SA algorithm and the local search algorithm. At the beginning, T value is high, may accept the poor deterioration solution; with decreasing T value, can only accept the better deterioration solution, finally, while T value is near 0, will not accept any deterioration solution. That is, SA algorithm can jump out of the local optimal trap, and then achieve the overall optimal solution of the combined optimization problem. In addition, SA algorithm's convergence rate is determined by the choice of the parameters T_k and L_k (k = 0, 1, 2 …), T_k is the control parameters T value while the k times iteration of M algorithm, L_k is the transformation number while the k times iteration of M algorithm.

III. Applications of SA

A. Evaluation index System Construction

Constructing a scientific and systemic evaluation index system of the resource-saving society, this is the important basis of evaluating objectively and reflecting the saving degree. In this paper, follow a series of principles, including scientific, comprehensive, workable, practical, independence and guiding, we selected 25 indicators to build a resource-saving society evaluation index system:

1） Economy saving index

The economy saving index, including seven indicators: the energy consumption unit GDP (U_1), the power consumption unit GDP (U_2), the water consumption unit GDP (U_3), the energy consumption unit industrial added value (U_4), the transport land (U_5), the urban industrial water saving degree (U_6), the comprehensive utilization of industrial solid waste (U_7).

2) Society saving index

Social saving index, including five indicators: the occupied land area of urbanization (U_8), the urban per capita water consumption (U_9), the buses amount of per 10 thousands people (U_{10}), the water-saving area of various regions (U_{11}), the gas production total amount of methane-generating pit in rural (U_{12}).

3) Environment support index

Environment support index, including seven indicators: the proportion of environmental pollution control investment in the GDP (U_{13}), the handling capacity of the wastewater treatment facilities (U_{14}), the urban sewage treatment rate (U_{15}), the proportion of natural region protection area in the jurisdiction region (U_{16}), the Green coverage of city region (U_{17}), the product output of "three wastes" comprehensive utilization (U_{18}), the urban wastes harmless treatment rate (U_{19}).

4) Science and technology support index

Science and technology support index, including six indicators: the number of professional and technical personnel in the state-owned enterprises or institution (U_{20}), the number of science and technology activities personnel in the large and medium-sized industrial enterprises (U_{21}), the internal expense of R&D expenditures in the large and medium-sized industrial enterprises (U_{22}), the contract value on the technology market (U_{23}), the contract value on the foreign technology introduction (U_{24}), the geological exploration work costs (U_{25}).

B. Example

1) A Case Study

In this paper, we use the relevant information of Hebei Province a certain area in 1995-2005 as subject investigated, and establish neural network model. First of all, we carry out the classification and standardized treatment of the input and output data, for example, the classification standard of urban per capita water consumption(m3)is:
U9<5000,5000≤U9≤7000,7000<U9≤9000,U9≥9000; the other indicators classification is similar. The classification standard of evaluation criteria is: I≤0.1; 0.1<II<0.3; III≥0.3. For the evaluation index, make the three-dimensional space and three-axis coordinates as the expected output value, respectively: I level 0.9, 0.1, 0.1; II level 0.1, 0.9, 0.1; III level 0.1, 0.1, 0.9. Select 15 learning modes, the input data as the following:

U1=(10,7,5,0,3,8,8,8,2,5,0,6,4,3,7）
U2=(0,5,3,0,9,10,7,7,2,8,6,7,0,0,0)
U3=(10,8,8,2,7,5,5,7,9,0,0,5,7,8,3)
U4=(10,9,6,6,9,0,0,1,3,7,7,8,7,6,3)
U5=(10,4,6,2,1,1,0,0,4,7,9,9,5,7,4)
U6=(0,6,7,6,4,9,9,0,7,6,3,3,7,8,10)
U7=(10,9,10,6,7,5,5,8,5,8,3,0,0,2,8)
U8=(10,8,8,8,8,2,8,0,7,8,6,3,3,1,5)
U9=(0,7,6,5,8,10,4,6,8,5,2,0,8,0,6)

U10=(0,7,6,8,4,10,10,5,0,8,1,5,7,4,6)
U11=(10,6,10,3,5,6,7,5,9,9,0,0,0,2,7)
U12=(0,1,1,2,3,7,6,7,7,6,7,8,7,8,10)
U13=(0,10,6,7,5,8,8,9,10,8,2,0,0,8,3)
U14=(10,10,3,9,0,5,5,8,4,6,8,4,4,2,8)
U15=(10,4,7,2,1,5,0,0,3,8,5,4,6,8,9)
U16=(0,0,7,7,8,5,5,1,1,0,10,8,8,5,9)
U17=(10,9,10,7,9,3,6,0,8,8,6,8,3,6,4)
U18=(10,4,4,3,2,0,7,7,4,6,9,9,1,1,0)
U19=(0,10,0,2,6,3,3,7,8,6,5,5,8,7,0)
U20=(0,0,3,3,6,7,6,7,8,8,2,10,4,4,7)
U21=(10,2,6,7,7,0,0,4,6,6,3,2,1,7,8)
U22=(10,6,7,5,5,3,2,0,3,3,3,1,0,0,0)
U23=(10,5,5,7,3,0,0,1,3,4,1,7,9,4,3)
U24=(0,0,4,8,8,3,9,4,3,6,3,10,3,6,7)
U25=(10,4,6,7,7,3,3,0,0,1,0,8,4,9,9)

The 15 expected output value: (II, I, III, II, III, II, III, III, II, III, III, I, III, II, III).

The input and expected output in 2006 is (9,6,9,7,3,0,2,1,9,1,7,8,6,8,2,9,1,5,9,2,7, 1,7,4,9, □). We compiled two kinds of network model procedures using VB6.0 and then compared each other. Use the traditional BP network, after trial, when the import layer has 25 neurons, the hidden layer has 20 neurons, and the output layer has three neurons, the model can get the more satisfied results (0.1999879, 0.1097926, 0.1114625).

We could get the similar results using BP network based on SA. But when the number of hidden layer neurons is beyond 25, the calculation result is not satisfactory through using the traditional BP network. When the number of the hidden layer neurons is 30, the comparison of total measurement error (Σ E) (15 samples) between the two kinds of model is shown as table I.

TABLE I. THE COMPARISON OF MEASUREMENT ERROR

Learning method	First time	Second time	Third time
Grads cline	11 436 89	11 428 63	7 974 32
SA	11 439 21	11 431 95	11 435 02

CONTINUE TABLE

Learning method	Fourth time	Fifth time
Grads cline	11 438 87	7 472 32
SA	11 440 35	11 440 46

2) The application of SA

In this paper, we selected three regions as the application research samples, respectively: North China, including Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia Autonomous Region; Central China, including Henan, Hubei, Hunan; Northeast China, including Liaoning, Jilin and Heilongjiang. Use SA to evaluate the resource-saving society issue of the provinces in the three regions, the evaluation results and sort ranking are shown as table II.

TABLE II. THE TOTAL SAVING INDEX EVALUATION RESULTS AND SORT RANKING OF THE PROVINCES, MUNICIPALITIES AND AUTONOMOUS REGIONS IN NORTH CHINA, CENTRAL CHINA, NORTHEAST CHINA

Region	Evaluation results	Sort ranking
Beijing	I	1
Hebei	I	2
Henan	I	3
Tianjin	I	4
Hubei	II	5
Hunan	II	6
Liaoning	II	7
Heilongjiang	II	8
Shanxi	III	9
Jilin	III	10
Inner Mongolia	III	11

From Table II results, it is easy to see that the sort ranking of resource-saving society; the provinces' economic development level and the overall development level, both of them are not entirely consistent and even exist the greater discrepancy. It is not application flaws of SA itself, mainly because in some areas, economic is underdevelopment, society level is low, the invasive damage to the resource is less, resulting in less use to the resources, less waste, and more saving. Therefore, we can not say simply that the resource-saving situation of these areas is better than the other areas.

Some economy developed areas; the total index score of the resource-saving society is not high, the total saving sort ranking is not higher, the resource-saving society construction situation is on middle and lower level among the various regions. In theory, in these areas, because of the more developed science and technology, the stronger cultural and environmental protection awareness, the more stringent policy measures and other reasons, the resource-saving society construction situation should be better than other areas. But on the other hand, the developed economy, the strong resource-based industries, which cause the larger resources use quantity and more waste, thus, more savings, also more waste, at last, waste is greater than saving. Overall from the outside, the appearance has been shown that the resource-saving situation is unsatisfactory.

So, when compare and analyze the actual region, we should carry out in the same economy level and basis and make the results more comparable.

From Table II results, we can see that in terms of the three regions, including North China, Central China and Northeast China. Central China, where the gap of the resources-saving society construction situation among the three provinces is little, and stand the middle and upper level; Northeast China, where the gap of the resources-saving society construction situation among the three provinces is also little, but stand the middle and lower level; North China, where the situation is complex relatively and the gap of the resources-saving society construction situation is larger.

It shows that North China has special political, economic and cultural background compared to Central China and Northeast China, the Beijing-Tianjin-Hebei region with a core of Beijing is gradually realizing the integration of the Matthew Effect and the nurturing effect, the resource-saving society index scores of Beijing, Tianjin and Hebei are relatively high. In this paper, we consider that the next strategy should be expanding the nurturing effect of Beijing and Tianjin in North China, to further extension from the Beijing-Tianjin-Hebei region, spurring Shanxi and Inner Mongolia Autonomous Region to achieve the sustainable development jointly, constructing the resource-saving society, and enhancing the overall strength of North China.

IV. CONCLUSIONS

(1) SA algorithm can seek the global optimization solution of the optimal problem through using the statistical mechanics views, which is a more advanced algorithm to solve the optimized problem. The method is relatively simple, which has almost no requirements to select the initial point, under normal circumstances, has also no restrictions to the problem's dimension. Moreover, SA algorithm is superior to the local search algorithm, where both in the final solution quality and its dependence on the initial solution, or in time's complexity.

(2) Through using simulated annealing principle, the mixed algorithm solved effectively the problem, which the training learning can not improve its performance after BP learning algorithm sinking into the local small area; in the event that guarantee not to reduce the learning speed, SA algorithm approach more quickly to the overall minimum, to find the overall minimum point. Example results show that the algorithm is feasible and effective. But the new model doesn't resolve the other issues of BP network, such as the slow convergence, the network hidden nodes selection, and so on, which need further study and resolve.

(3) In the practical application, SA algorithm is a heuristic algorithm, which many parameters need to adjust, such as the initial temperature, the temperature dropped programme, the iteration length and rules termination when the temperature is fixed, and so on, so the method needs to adjust factitiously. The factitious factors, such as the understanding level to the problem, the collocation of the parameters and rules, which will cause the computing results difference. Therefore SA algorithm needs to further study.

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