A simulation model of system dynamics for evaluating dynamic changes of priority sectors in county industry

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Abstract

As the developing speed of the county industry economy depends to a large extent on the developing speed of the whole county economy, it is the key of success of the county economy planning that how to bring the region superiority into full play, and that which of priority sectors in industry should be developed under the circumstances of limited funds, resources and sources of energy. For this reason, it is difficult to get a united opinion when discussing that which is priority sector in undertaking a county economy planning.

A system dynamics model (SD2 model) suggested in this article is actually one of the model group of system dynamics. The model can be used to evaluate those priority sectors dynamically through being introduced the method of multiobjective decision analysis. In the article the writer also introduce a simple method of preference ranking about equality or inequality weight targeted values in a period of time, so the scientific quantitative basis can be supplied for working out the county economy planning.

There are several characteristics of SD2 model. It can be used to dialogue between person and computer conveniently, to compare and analyse multi-plannings, to give the user dynamic economy indicators and benefit indicators, e.g., fixed assets, labors, rate of profits and taxs to funds, etc. If cutting out the rate of output values of sectors in the evaluating indicators, we can obtain an evaluating indicator for general economy benefits.

The simulation results of the SD2 model have supplied an important reference for working out a county economy planning used in practice effectively. Of course, this model can still be used for the same questions in other sectors or in larger regions.

THE WHOLE MODEL DESIGN

The SD model group composed of three system dynamics models is set up according to real circumstances of a county. The total computer programs of the SD simulation are compiled in DYNAMO language. The developing sketch of the national economy and the changes of the industrial structure of a county between 1980 and 2000 are all drawn up.

The SD2 model described emphatically in this article is only a part of the real SD model system, which is composed of a forerunner model group and a SD model group, and the former term involves a predicted model set and an industry production function model set. The SD model group involves the SD1 model to the national economy of the county and the SD3 model to the supply of the sources of energy of the county in addition to the SD2 model to the synthetical evaluation of the priority industry sectors. A diagram which illustrates the relationships among the factors is shown in Figure 1.

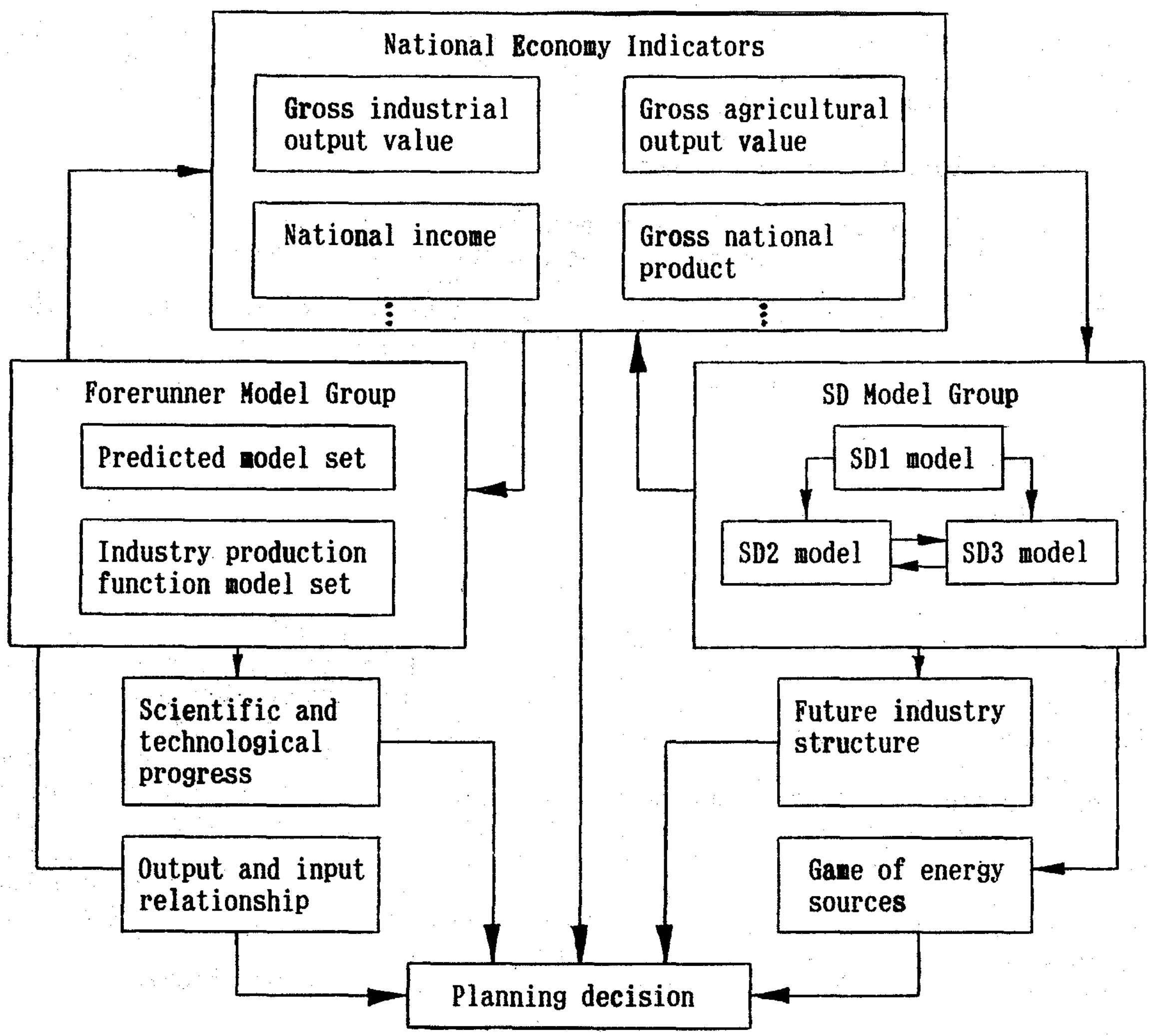

FIGURE 1 SD Model System

DESCRIPTION OF THE SD2 MODEL

1. Introduction of the problem

The national economy system of a county, though small, is a complete open system involving a satisfactory variety of sectors. A great quantity of industrial and agricultural products have to be sent to the markets outside the county to change into the funds of flowing back. Those necessary mechanized equipment, electric power, etc., have to be imported from outside and some funds, of course, also flow out of the county. The importance of open system is that it ensures the efficient exchanges from material flow to capital flow and then accelerates the expanded reproduction. The funds of developing county economy principally depend on accumulation itself in addition to the opportunity (foreign funds, etc.). The greater part of county revenues still rely upon the county industrial accumulation. In the period of the Sixth Five-Year Plan, six priority lines, i.e., chemicals, machines, building materials, food products, textiles, glass and ceramics, have been formed in Qichun county industry. However, how to identify the more important one in the six sectors? Which of these will become a lead line in the county industry once the investment decision is fixed? What are future general layout and state? There is an important referential sense for working out the county economy planning in the policy analysis about these problems, and there is also great significance for the county decision-makers who are working out the present policies. For the purpose of solving similar problems, the model SD2 is set up.

2. Procedure of building models

Let the essential element set of industry economy S be denoted by $\Gamma(S)=\{A_i/A_i\subseteq\tilde{R}^n, i=1,2,...,m\}$, and let the relation set for the elements above be denoted by $R(\Gamma)=\{R_{ij}/R_{ij}\subseteq A_i\times A_j, i,j=1,2,...,m\}$. Note that the essential element set and the relation set here, which don't involve any quantitative values, are all the concept sets. Then the system S can be corresponded to the S_D system of system dynamics through mapping (single-valued mapping in general) as follows:

$$f: S\rightarrow S_D,\ \Phi: R\rightarrow R^*.$$

so that, $\Gamma(S_D)=\{Q_i/Q_i\subseteq\tilde{\tilde{R}}^n, i=1,2,...,m\}$,

$$R^*(\Gamma)=\{R^*_{ij}/R^*_{ij}\subseteq Q_i\times Q_j, i,j=1,2,...,m\}.$$

Through the above exchanges the qualitative elements in S are converted into the quantitative units in S_D and the qualitative casual relations in S are converted into the quantitative flows (material flows or information flows). So the language models have been changed into the S_D flow diagrams, then the key factors are found out and the variable types are ascertained. Obviously the funds of influencing the circulation of the county system are the key factors of limiting and promoting the county industry economy. Funds are the critical points, since they can be considered either the course of production, or the results of production. Thus the fund should be determined to be a level variable. The decision variable is generally denoted by CLIP function or TABLE function. Its changes directly affect the accumulations of levels and then affect the circulations of all the units as well as the whole system.

In order to be clear it can be showed below with the method of set theory:

Varible set: $\Gamma(Q_i)=\{X_i, R_i, V_i, PU_i, Y_i\}$

Relation set: $\Gamma(R^*_{ij})=\{FI_{ij}/FI_{ij}\subseteq Q_i\times Q_j\}$

where, X -- state variable set
R -- decision variable set
V -- auxiliary variable set
PU-- parameter set or input variable set
Y -- output variable
FI-- flow coupling variable

Some decision variables in SD2 model are defined by forerunner model group according to the practical indicator values of the county in the period of the Sixth Five-Year Plan. A few of external variables needed to change into internal variables can be denoted by TABLE functions in time series. In the course of determining the structure and parameters of the system, we lay stress on listening to the opinions of relative decision-makers who have rich practical experiences.

3. Model Structure

SD2 model is a system dynamics model of evaluating dynamic changes comprehensively in the county industry. Funds play a leading role and the benefit indicators are prominent in the model. Let the fixed capital of each sector be a level variable, and

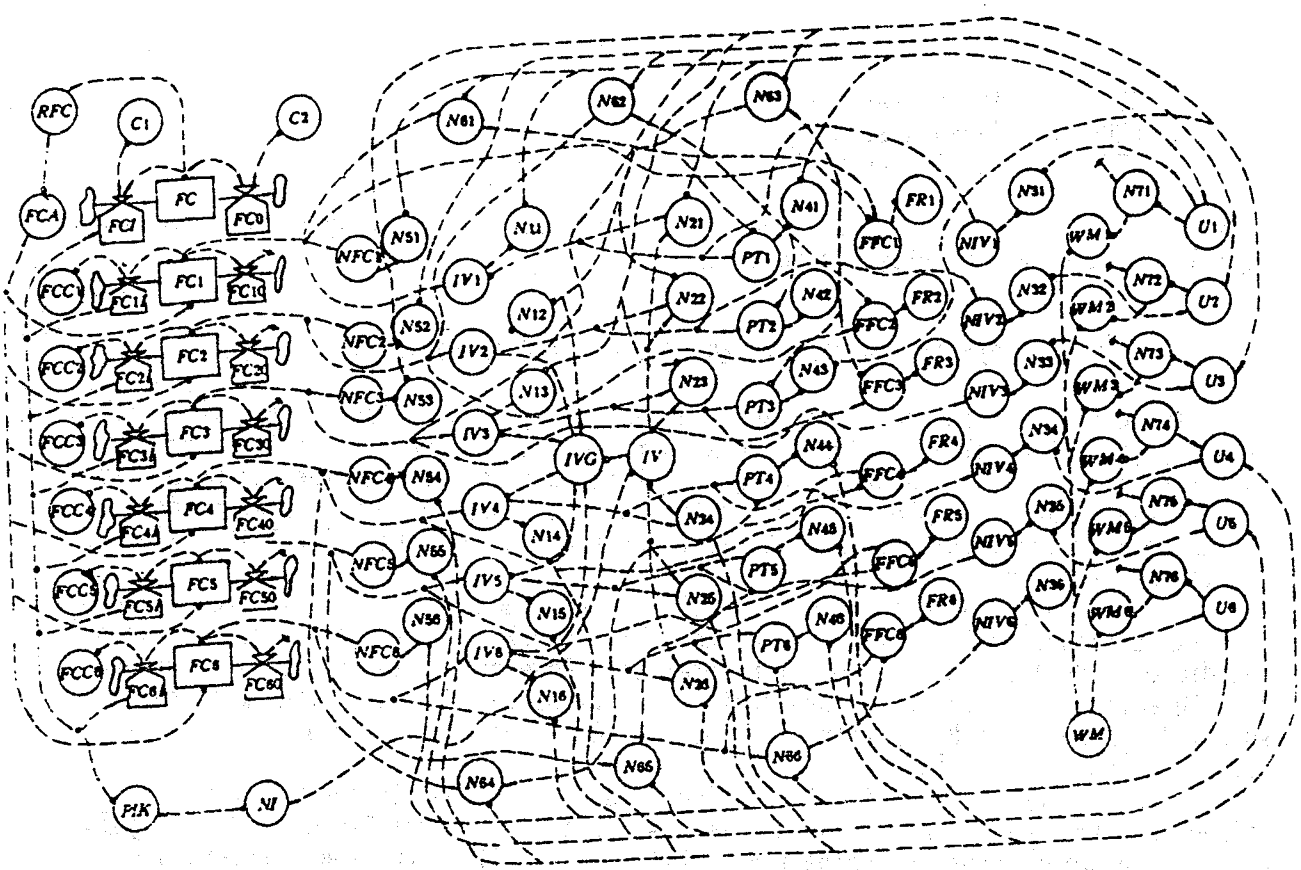

Figure 2 The flow diagram of the SD2 Model

the changes of future industry structure are implicitly involved in the changes of growth rates of fixed capitals for the six priority lines. Let the other benefit indicators be auxiliary variables.

Figure 2 shows the model flow diagram in which there are 14 flow rate variables, 93 auxiliary variables, and 320 equations. The simulation period of time is from 1980's to 2000's.

It is the principal character that a dynamic objective function of evaluating sectors comprehensively is set up through introducing the decision analysis of multiobjective function. They are represented as follows:

$$\text{Max } U_i(t)=\prod_{p=1}^{6} N_{pi}(t)/N_{7i}(t), \quad (i=1,2,\ldots,6),$$

where, $N_{1i}(t)=IV_i(t)/FC_i(t)$, $N_{2i}(t)=IV_i(t)/IV(t)$,

$N_{3i}(t)=NIV_i(t)/IV_i(t)$, $N_{4i}(t)=PT_i(t)/IV_i(t)$,

$N_{5i}(t)=NFC_i(t)/FC_i(t)$, $N_{6i}(t)=PT_i(t)/(NFC_i(t)+FFC_i(t))$,

$N_{7i}(t)=WM_i(t)/IV_i(t)$, $(i=1,2,\ldots,6)$.

IV -- gross industrial output value of county
IV_i -- industrial output value of i-th sector
FC -- fixed assets
WM -- labor number
NIV-- net value of industrial output

PT -- profit and tax yields
NFC-- net fixed assets
FFC-- circulating capital

i=1,2,...,6 above represent chemicals, machines, building materials, food products, textiles, glass and ceramics, respectively.

SIMULATION RESULTS AND EVALUTATION ANALYSIS

We design fifteen distinct investment schemes to proceed to the policy simulation in using the SD2 model on an IBM Personal Computer. After considering the county industry base, natural resources, external circumstances, etc. in the course of simulation, the planning people and the county decision makers determine a more ideal scheme about which plot-outs and table-outs of simulation results for $U_i(t)$ illustrated in Figure 3 and Table 1 respectively.

The $U_i(t)$ value of sequencing of each line in the industry at any time point can be directly attained on the curves or in the table. Usually these output results can be immediately supplied for the decision reference. However, it is necessary to proceed to mathematics analysis if the sequencing results of the period of time must be supplied, whereas the $U_i(t)$ values of the six lines transform alternately. A useful method is described below:

Firstly a×n p dynamic matrix of ordering value (n time points and p sectors) is defined as: $A \triangleq (a_{ij})_{n\times p}$, natural number set $E=\{n/n=1,2,\ldots\}$, set $E_p=\{q/q=1,2,\ldots,p\}\subseteq E$, $a_{ij}\in E_p$, the weight ordering value vector $P=(p,p-1,\ldots,1)^T$. Thus the frequency row vector of p-dimensional ordering value can be established according to the emergence frequency of element q of each column vector A_i in the matrix A, then p row vectors of p-dimension form a p×p matrix S of ordering value frequence. Hence the column vector $R=S\cdot P$ is a ultimate ordering vector of p-dimension that we expect to obtain.

Using the above-mentioned method we can proceed to the quantitative analysis as follows:

The sequencing results between 1981 and 1985 can be derived first. Here n=5 and p=6.

$$A=\begin{bmatrix} 1 & 2 & 4 & 5 & 6 & 3 \\ 1 & 4 & 3 & 5 & 6 & 2 \\ 2 & 5 & 4 & 6 & 3 & 1 \\ 2 & 4 & 3 & 6 & 5 & 1 \\ 2 & 5 & 3 & 6 & 4 & 1 \end{bmatrix}, \quad P=(6\ \ 5\ \ 4\ \ 3\ \ 2\ \ 1)^T$$

The A matrix of ordering value above can be easy obtained from Table 1 (where, a_{ij} is the weight ordering value of the j sector in the i year).

The first column of matrix A shows that the number of emerging frequency of element "1" is equal to 0.4, that the number of emerging frequency of element "2" is equal to 0.6. Thus the frequency row vector of ordering value S =(0 0 0 0 0.6 0.4), The other five row vectors can be got alike. Thus

$$S=\begin{bmatrix} 0 & 0 & 0 & 0 & 0.6 & 0.4 \\ 0 & 0.4 & 0.4 & 0 & 0.2 & 0 \\ 0 & 0 & 0.4 & 0.6 & 0 & 0 \\ 0.6 & 0.4 & 0 & 0 & 0 & 0 \\ 0.4 & 0.2 & 0.2 & 0.2 & 0 & 0 \\ 0 & 0 & 0 & 0.2 & 0.2 & 0.6 \end{bmatrix}$$

Hence $R=S\cdot P=(1.6\ \ 4\ \ 3.4\ \ 5.6\ \ 4.8\ \ 1.6)^T$.

Table 1 The $U_i(t)$ values of synthetic evaluation function

TIME \ U_i	U_1	U_2	U_3	U_4	U_5	U_6
1980	2.2510	36.601	7.510	162.37	113.80	1.5467
1981	0.1044	3.522	13.864	130.80	149.87	3.6281
1982	0.4554	15.919	13.221	70.83	116.63	2.7958
1983	0.8204	18.959	6.012	31.85	13.16	0.6203
1984	1.4268	21.307	8.218	37.10	27.06	0.6867
1985	1.8455	25.066	6.461	29.17	23.10	0.0328
1986	1.8308	24.427	6.637	29.71	23.93	0.0314
1987	1.8150	23.786	6.812	30.23	24.77	0.0300
1988	1.7979	23.145	6.987	30.74	25.62	0.0287
1989	1.7797	22.505	7.161	31.24	26.49	0.0274
1990	1.7604	21.868	7.334	31.72	27.36	0.0262
1991	1.7672	21.161	7.826	32.13	29.20	0.0253
1992	1.7721	20.456	8.343	32.51	31.12	0.0245
1993	1.7754	19.754	8.886	32.86	33.15	0.0236
1994	1.7768	19.058	9.454	33.18	35.27	0.0228
1995	1.7767	18.369	10.049	33.48	37.49	0.0220
1996	1.7182	17.125	10.331	32.67	38.54	0.0205
1997	1.6594	15.943	10.607	31.84	39.57	0.0191
1998	1.6006	15.824	10.876	30.99	40.57	0.0177
1999	1.5419	13.766	11.138	30.12	41.55	0.0165
2000	1.4835	12.767	11.392	29.24	42.50	0.0153

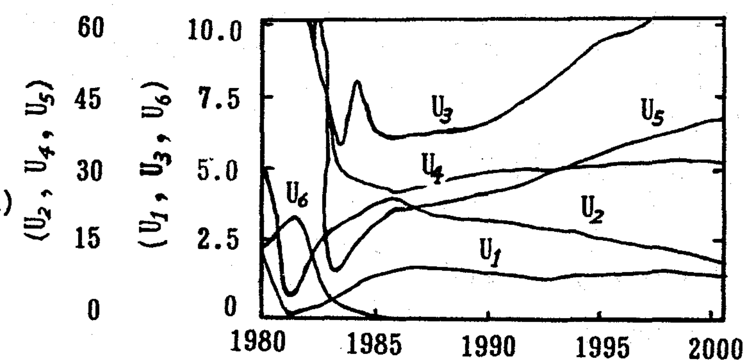

Fig. 3. The diagram of curves of the $U_i(t)$ values $(i=1,\ldots,6)$

A conclusion can be drawn as follows from the six-dimensional ordering vector gained ultimately: During the period of the Sixth Five-Year Plan the sequencing of important degrees of the six sectors is separately food products, textiles, machines, building materials, chemicals, glass and ceramics.

The sequencing of the priority lines in the county industry from 1990 to 2000 is given below. In order to simplify the question, the matrix of ordering value is set up corresponding to $U_i(t)$ value at three points (i.e., A.D. 1990, 1995, 2000).

$$A=\begin{bmatrix} 2 & 4 & 3 & 6 & 5 & 1 \\ 2 & 4 & 3 & 5 & 6 & 1 \\ 2 & 4 & 3 & 5 & 6 & 1 \end{bmatrix},\quad S=\begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1/3 & 2/3 & 0 & 0 & 0 & 0 \\ 2/3 & 1/3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}.$$

Hence $R=S\cdot P=(2\quad 4\quad 3\quad 5.3\quad 5.7\quad 1)^T$.

Consequently the sequencing of important degrees of the six sectors are textiles, food products, machines, building materials, chemicals, glass and ceramics, respectively.

It is necessary to explain the SD2 model additionally as follows:

1. The market sales of products and the supplies of raw materials are not involved in the objective function for synthetical evaluation. Of course it is such a result to the past production and management, and we suppose that the future production and management can be satisfied through making efforts.

2. The consuming indicator of source of energy power is not represented in the synthetical evaluation objective function because of the compatibility between the sequencing of economy consuming of source of energy power and that of the SD2 model. Any change will not happen to the sequencing of the model even if the indicator above is put in the objective function.

3. The multiplication-division analysis of multiobjective function is applied in the article when the synthetical evaluation objective function needs to be calculated. With application of the method, each indicator in the counting formula has an average weight generally, but the differences of the importance among the indicators are present in the real system. Therefore the article presents an exponent weight method.

The multiplication-division method is a method with which a multiobjective question can be changed into a single objective one. Usually its representation is in the follow:

$$\text{Max } F(x)=\prod_{i=1}^{k} f_i(x)/\prod_{i=K+1}^{N} f_i(x),$$

where k objectives must be maximal to the numerator and n-k ones must be minimal to the denominator, and the exponent of each indicator is equal to 1. Suppose the exponent weight (i=1,2,...,k) is showed to the k objectives in the numerator, the follows can be got:

$$F(x)=\prod_{i=1}^{K} (f_i(x))^{\lambda_i}/\prod_{i=K+1}^{N} f_i(x),$$

then

$$\text{Ln}(F(x))=\sum_{i=1}^{K}\lambda_i \text{Ln}(f_i(x))-\sum_{i=k+1}^{N}\text{Ln}(f_i(x)).$$

Now a linear weight representation has been gained through the logarithmic conversion.

where $\lambda_i \begin{cases} >1 & \text{if } f_i(x)>1 \\ =1 & \text{if } f_i(x)=1 \\ <1 & \text{if } 0<f_i(x)<1 \end{cases}$ to the key objective.

Usually the rate of the net output value and the ratio of profit and tax to funds are considered as key objectives, since $N_{3i}<1$, $N_{6i}>1$ (illustrated with the profits and taxs to a hundred yuan (the monetary unit of China)).

Thus $\lambda_3<1$ and $\lambda_6>1$.

The various simulation solutions of $U_i(t)$ value can be obtained with corresponding to the various λ_i. When $\lambda_3=0.7$ and $\lambda_6=1.3$, for example, the ordering vector in the period of the Sixth Five-Year Plan is $R=(1.6\ \ 3.8\ \ 3.4\ \ 5.6\ \ 4.6\ \ 1.6)^T$ after being computed. Comparing this vector with the former one under the condition of the equal weight above we know that the two sequencings are more or less alike, and the sequencing in the time period between the 1985's and the 2000's can be got directly from the curve diagram and the table.

4. The model can also export various dynamic indicators of each sector, e.g., net value of output, net fixed assets, profit and tax yield, labor number, circulating capital, etc. between the 1985's and the 2000's according to the decision needs.

5. The simulation can be used for evaluating the synthetical economy benefits of various sectors if the ratio of output value N_{2i} is rejected from $U_i(t)$.

CONCLUSION

The SD2 model introduced in this paper is a key one in the SD model group. Combining with the relative time series data collected and a number of parameters derived from the forerunner model group, the model has sought to show that the method of decision analysis of multiobjective function is introduced in the system dynamics model to proceed to the dynamic evaluation for the priority sectors. The model also gives us a simple method about the sequencing in a time period under the condition of the equal weight or the non-equal weight. The simulation solution of the model provides a quite good quantitative basis for working out the Qichun county economy planning.

The applying region of this model can be extended into the same questions of the other sectors or the larger regions.

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