

Modeling and simulation of SD-FMOP for circular economy planning *

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Abstract. In this paper, we concentrate on developing the SD-FMOP which takes the meaning of system-dynamic (SD) model for county circular economy research with fuzzy multi-objective programming. We set up a series of formulations based on the data of the region by operating on statistical program for social sciences (SPSS). Through fuzzy multi-objective programming (FMOP), we factually optimize the system to get the optimum value of the sensitive parameters in the SD model. Then we build a system dynamics model and simulate the evolving process of this county system. Finally we get the results which can provide scientific evidence to the circular economy development in the area.

Keywords: circular economy, system dynamics, SD-FMOP, simulation

1 Introduction

circular economy claimed that economic behavior has to be organized in a feedback flow such as resource-product-renewable resource^[9]. The main characteristic of circular economy is low exploitation, high usage, low pollution. All the resources and energy can be utilized reasonably in order to make the economy raised while reducing the negative influence to the environment.

In such a complex and huge system, many objective of production or restriction of circumstance could not be described and calculated precisely. There is widespread evidence that the exact numerical value are very difficult to obtained. For instance, the increment and decrement of land, the production value of industry, the minimum or maximum quantity of population etc.. The SD-FMOP takes the meaning of system-dynamic (SD) model for county circular economy research with fuzzy multi-objective programming (FMOP). The System dynamics, which is a computer-aid approach and theory for analyzing and solving complex systems, is a widely applied in many places. It includes work in corporate planning and policy design^[1], economic behavior^[4], public management and policy, biological and medical modeling, energy and the environment, theory development in the natural and social sciences, dynamic decision making, complex nonlinear dynamics, software engineering, and supply chain management. On the other hand fuzzy multi-objective programming offers a powerful means of handling optimization problems with fuzzy parameters. This is caused to use fuzzy multi-objective optimization method with fuzzy parameters. The FMOP were applied and solved many problem such as: fuzzy traffic controller^[17], restoration service in Distribution Systems^[18], grid resource management^[19], resource allocation, etc. However, there are few application on circular economy planning. Conventional optimization methods assume that all parameters and goals of an optimization model are precisely known. But for many practical problems there are incompleteness and unreliability of input information.

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The character makes the inosculation of SD and FMOP creditable and reasonable. In this paper, we will conduct the research on circular economy by the model of system dynamics (SD) with fuzzy multi-objective programming (FMOP).

The rest of the paper is organized as follows. In section 2, the SD-FMOP model for economy planning will be set up and the solution method will be stated after the system was optimized by FMOP. Next, in section 3, we simulate the system dynamic model with software named VENSIM and the analysis of region cycle economy planning is in what follows. The presentation of conclusion is in section 4.

2 SD-FMOP for cycle economy planning

We have simply mentioned the SD and FMOP model. They adapt to analysing some complex systems and solving the problems which input or output parameters are uncertain. These contents were thorough studied and applied widely. However, the work of combining of these two and their solution methods and their application on cycle economy planning are still worth doing.

2.1 Analysis and building of SD model

To set up a system simulation model, we must analyze this region system firstly. We analyze the causality and give the causality chart, then make statistical analysis of the parameters in the system.

2.1.1 Causality

The aim of SD model for region system simulation is:

- (1) To reflect the relationships among all the parameters in the system objectively.
- (2) To simulate the evolving process of the whole system.
- (3) To discuss the behavior mode of the system development and to give the support of the decision-making.

To analyze the causality qualitatively, we can express this complex system problem in a concise and systemic way. System dynamics thinks that, any two factors in the same system must have positive correlation, negative correlation or no correlation. Positive correlation shows that one factor's increase will bring another factor's increase. On the other hand, negative correlation shows that one factor's increase will bring another factor's decrease. No correlation shows that two factors have no obvious direct correlation, one factor's change will not bring another factor's change directly.

The development of economy brings the increase of financial revenue, and this will bring the increase of investment in social security, education and infrastructure. The increase of investment will advance the population quality and population scale etc.. This may influence the development of three pillar industry, and influence the economy level further. The increase of population may impact the usage of resources and the pollution. At the same time, the high speed of development will have a strong impact on the environment and resources. Society, economy, environment and resources are connected together. Every factor impact and effect each other to form a dynamic organism.

2.1.2 Parameter

The parameters can be divided into state variable, rate variable, auxiliary auxiliary and constant. We give a concise introduction in the following.

- (1) State variable: the variable can accumulate the input variable and (or) output variable. S in short.
 - (2) Rate variable: the variable represents the input or output variable in the state variable equation. R in short.
 - (3) Auxiliary variable: the variable has the auxiliary effect in the feedback system. A in short.
 - (4) Constant: the value of this variable doesn't change in one simulation process. C in short.
- All the statistical parameters are compiled in Table1.

Table 1: Statistical parameters table

parameter	unit	type
quantity of forest	a unit of area	S
forest cover rate	percentage	A
new forestation area	a unit of area	R
forest exploration area	a unit of area	R
returning land for farming to forestry	a unit of area	A
other forestation area	a unit of area	C
region area	a unit of area	C
town area	a unit of area	A
town virescence area	a unit of area	S
town virescence rate	percentage	A
farming area	a unit of area	S
farming area increment	a unit of area	R
farming area decrement	a unit of area	R
other farming area decrement	a unit of area	C
average farming area	a unit of area/person	A
foodstuff planting area	a unit of area	A
production value of first industry	ten thousand yuan	A
production value of agriculture	ten thousand yuan	A
production value of forest industry	ten thousand yuan	A
production value of stockbreeding	ten thousand yuan	A
production value of fishery	ten thousand yuan	A
eligibility rate of waste water	percentage	A
total quantity of water resource	ten thousand ton	S
water supply quantity	ten thousand ton	R
quantity of water in need	ten thousand ton	R
average water quantity for life	ten thousand ton	C
quantity of water for life	ten thousand ton	A
quantity of water for irrigation	ten thousand ton	A
water for agriculture	ten thousand ton	A
cycle utilization rate of water	percentage	C
water for industry	ten thousand ton	A
cycle utilization rate of water	percentage	A
population scale	person	S
labor productivity of agriculture	ten thousand yuan/person	A
GDP of first industry	ten thousand yuan	A
GDP of third industry	ten thousand yuan	A
GDP of second industry	ten thousand yuan	A
production value of industry	ten thousand yuan	A
GDP	ten thousand yuan	A
GDP of last year	ten thousand yuan	A
financial revenue	ten thousand yuan	A
average GDP	ten thousand yuan/person	A
expenditure	ten thousand yuan	A
fixed assets investment	ten thousand yuan	A
reuse rate of waste water	percentage	A
rate of urbanization	percentage	A
farm population	person	A
nonagricultural population	person	A

system parameters. Now, we give some formulations in the following which can express the relations of the system partly.

$$\begin{aligned}
 \text{population} &= (\text{birth rate} - \text{death rate}) \times \text{population of last year} + \text{population of last year} \\
 \text{farming area} &= \text{farming area increment} - \text{farming area decrement} + \text{farming area of last year} \\
 \text{quantity of water resource} &= \text{water supply quantity} - \text{quantity of water in need} + \text{quantity of water of last year} \\
 \text{quantity of forest} &= \text{new forestation area} - \text{forest exploration area} + \text{quantity of forest of last year} \\
 \text{GDP} &= \text{GDP of first industry} + \text{GDP of second industry} + \text{GDP of third industry} \\
 \text{work force of society} &= \text{population} \times 1.175 - 106640 \\
 \text{water for industry} &= (\text{production value of industry} \times 0.004 / (1 + \text{cycle utilization rate of water for industry}) - \text{reuse rate of waste water} \times \text{quantity of waste water}) \times 3 \\
 \text{water for agriculture} &= \text{water for irrigation} / 0.4077 / (1 + \text{cycle utilization rate of water for agriculture}) \\
 \text{quantity of water in need} &= \text{water for industry} + \text{water for agriculture} + \text{water for life} \\
 \text{forest cover rate} &= \text{forest area} / \text{region area} \\
 \text{town virescence rate} &= \text{town virescence area} / \text{town area}
 \end{aligned}$$

2.2 Modeling and optimization of FMOP for SD

On the base of system analysis, we have set up the SD model for the region cycle economy planning. In such a complex and huge system, many objective of production or restriction of circumstance could not be described and calculated precisely. There is widespread evidence that the exact numerical value are very difficult to obtained. We introduce how to set up the fuzzy multi-objective programming (FMOP) model for this problem through an detailed example about farming land problem. In order to optimize the system to get the optimum value of the sensitive parameters in the SD model.

Here we will set up and adjust a FMOP through the example of farming land planning. Farming land is an important resource. Reasonable use and available control of it are key factor to region cycle economy. In succession, we roughly describe the farming land problem as a SD model.

The farming land problem describe as a SD model in Figure 2. Where FA and LFA denote farming area and farming area of last year respectively. Now we known that we can control the size of farming land by the way of controlling the other parameters. The variables named RL and ODC will be considered as fuzzy variables and be denoted as \widetilde{RL} and \widetilde{ODC} .

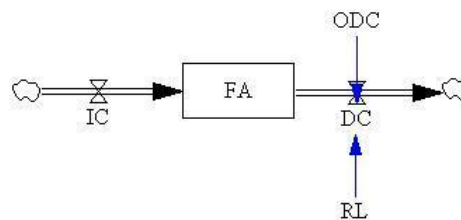


Fig. 2. SD model of farming land

Now, we give formulations in the following which can express the relations of the system.

$$\begin{aligned}
 FA &= IC - DC + LFA \\
 DC &= RL + ODC
 \end{aligned}$$

Then we indicate fuzzy variables, objective functions and constraints as follow:

\widetilde{RL} - returning land for farming to forestry

- \widetilde{ODC} - other decrement
- MQ - the minimum quantity of farming land
- IC - increment
- T - time (year)

The size of farming land can effect the production value of agriculture, forestry, industry and construction industry, so the objective functions are as follows:

- PVA - production value of agriculture
- PVF - production value of forestry
- PVI - production value of industry
- PVC - production value of construction industry

There are some constrains $g_j(x)$ objectively. As follows:

- $g_1(x)$ -the minimum value of average farming land per person
- $g_2(x)$ -the limited quantity of unexplored farming land
- $g_3(x)$ -the limit of decrement of farming land
- $g_4(x)$ -the limit of increment of farming land

Trough the analysis of history data, we have got some formulations. Now, we set up the FMOP model as follows:

$$\left\{ \begin{array}{l} \max PVA = 0.163(164319 + IC - (\widetilde{RL} + \widetilde{ODC})) - 7788.569 \\ \max PVF = 0.019\widetilde{RL} + 2735.669 \\ \max PVI = -5e^{-6}\widetilde{ODC}^3 + 0.0876\widetilde{ODC}^2 - 363.75\widetilde{ODC} + 448034 \\ \max PVC = -7e^{-8}\widetilde{ODC}^3 + 0.0011\widetilde{ODC}^2 - 4.3169\widetilde{ODC} + 7130.68 \\ \text{subject to :} \\ MQ/(195500(1 + 0.00965)^T) \geq 0.764 \\ IC \cdot T \leq 126587.55 \\ 164319 + (IC - (\widetilde{RL} + \widetilde{ODC})) \cdot T \geq MQ \\ IC \leq 5428 \end{array} \right.$$

where ORL , DC are assumed to triangular fuzzy variables according to statistical data. $\widetilde{RL} = (900, 1213, 1540)$ and $\widetilde{ODC} = (800, 1000, 1200)$.

According to Chance-Constraint Programming, we convert the above model to CCMOP model as follows:

$$\left\{ \begin{array}{l} \max[\overline{PVA}, \overline{PVF}, \overline{PVI}, \overline{PVC}] \\ \text{subject to :} \\ Cr\{0.163(164319 + IC - (\widetilde{RL} + \widetilde{ODC})) - 7788.569 \geq \overline{PVA}\} \geq \beta_1 \\ Cr\{0.019\widetilde{RL} + 2735.669 \geq \overline{PVF}\} \geq \beta_2 \\ Cr\{-5e^{-6}\widetilde{ODC}^3 + 0.0876\widetilde{ODC}^2 - 363.75\widetilde{ODC} + 448034 \geq \overline{PVI}\} \geq \beta_3 \\ Cr\{-7e^{-8}\widetilde{ODC}^3 + 0.0011\widetilde{ODC}^2 - 4.3169\widetilde{ODC} + 7130.68 \geq \overline{PVC}\} \geq \beta_4 \\ MQ/(195500(1 + 0.00965)^T) \geq 0.764 \\ IC \cdot T \leq 126587.55 \\ Cr\{164319 + (IC - (\widetilde{RL} + \widetilde{ODC})) \cdot T \geq MQ\} \geq \alpha_1 \\ IC \leq 5428 \end{array} \right.$$

We select direct solution method to solve this programming that is making use of GA. The result of this programming is showed in Tab. 2. Then we put this result to the SD model to do the simulation.

We communicate with the decision-maker about this result and they are satisfied with it. So we put this result to the SD model to do the simulation. On the other side, if they are not satisfied with the result, we should adjust the constrains or do much more calculation to get better result.

Table 2. Result

β_1	β_2	β_3	β_4	α_1
0.9	0.92	0.85	0.9	0.8
MQ	IC	T		
157550	1454.1	18		
PVA	PVF	PVI	PVC	
19017	2758.7	410640	6687.6	

3 Simulation and analysis

We put the value of sensitive parameters which got from the multi-objective programming model to the system dynamics model to do the system simulation with simulation software named VENSIM. We make the data of 2005 as initial data, initial time equal to 0 namely. We make year as the time unit, one year equal to one time step namely. We make 15 years as the extension of our study, final time equal to 15 namely. For this, we can get all the developing statuses from 2005 to 2020.

3.1 Results

Through the system dynamics model and simulation, we get a series of results. It shows in the following figures, from Fig. 3 to Fig. 12.

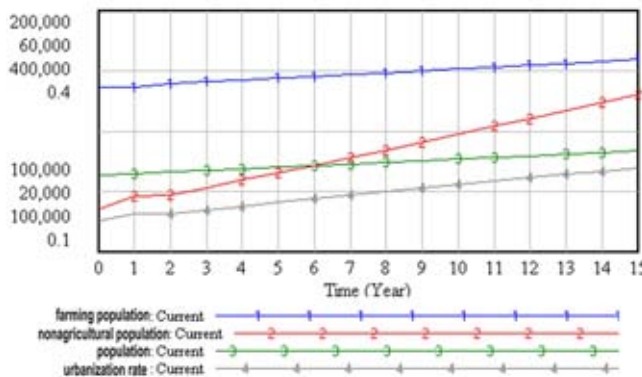


Fig. 3. population

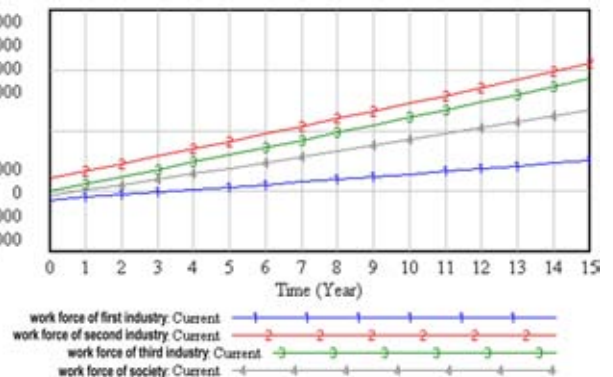


Fig. 4. work force

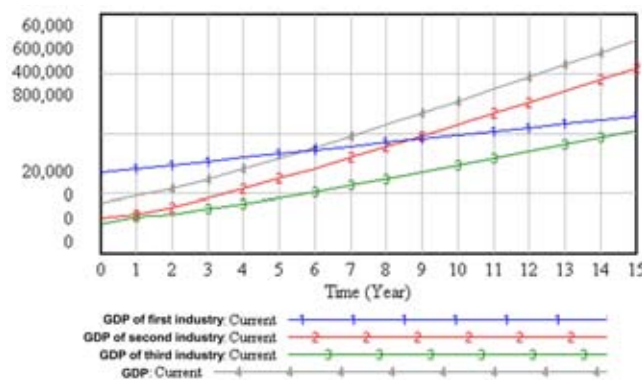


Fig. 5. GDP

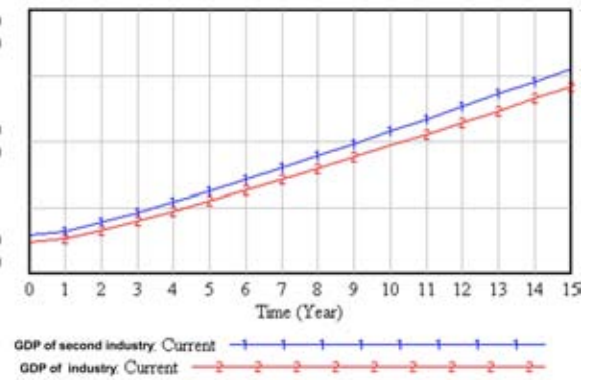


Fig. 6. GDP of second industry

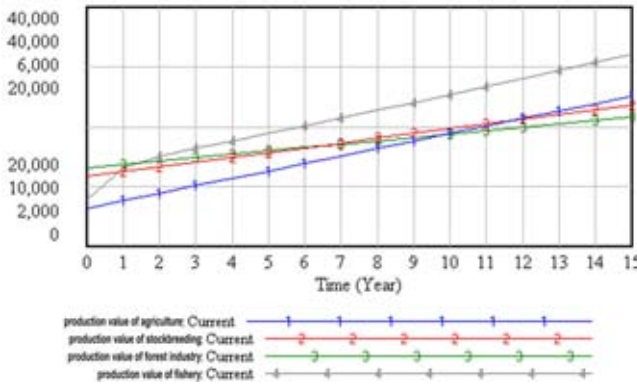


Fig. 7. Production value of first industry

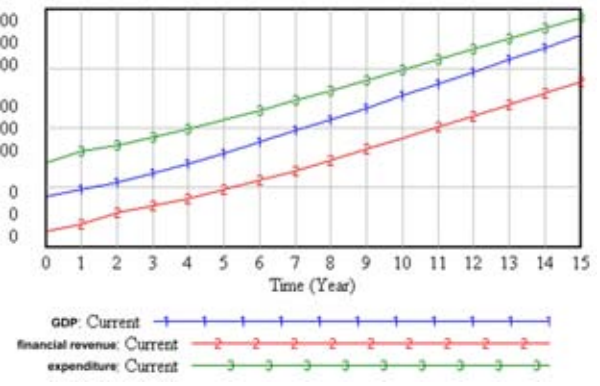


Fig. 8. financial revenue and expenditure

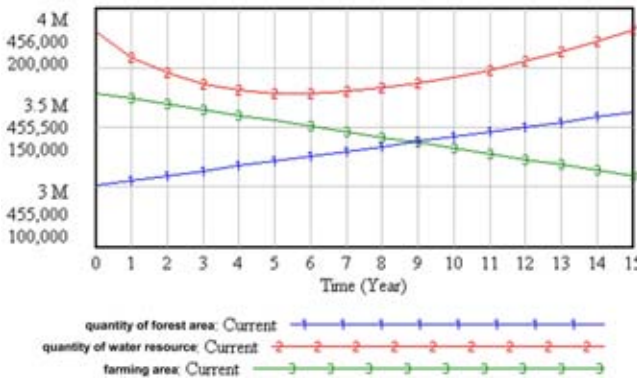


Fig. 9. resources

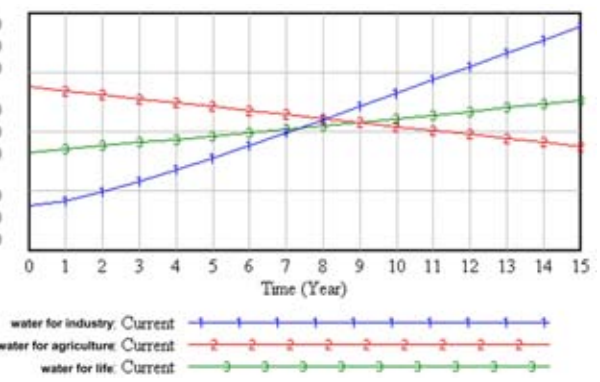


Fig. 10. water resource

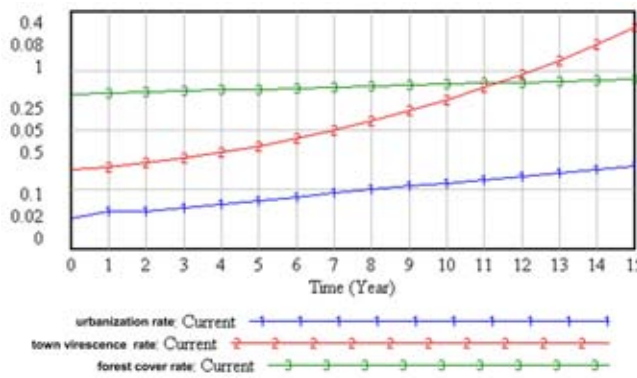


Fig. 11. urbanization, virescence and forest cover rate

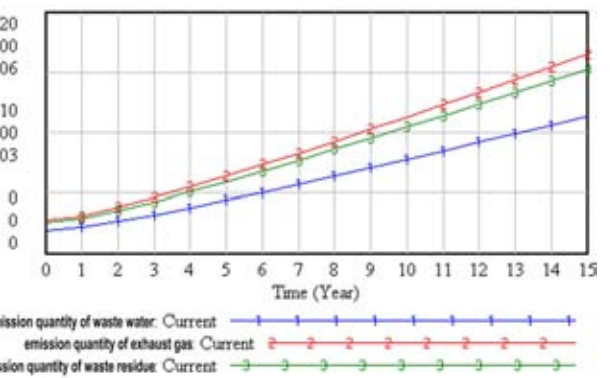


Fig. 12. pollution

3.2 Discussion

From all these figures above, we can get some information of the system evolution.

(1) GDP increases especially in the second industry and the third. The curve of GDP has the similar trend with that of the second industry. Thus we can say the second industry is important to the economy in the area and the government should pay more attention on it.

(2) population increases slowly, it will reach 205,000 at the end of year 2010. But the speed of non-agricultural population growth accelerates gradually. Urbanization speeds up because of the development of economy. The work force of first industry increases slowly, but in second and third industry, it grows faster. This may reflect that the two industries develop very fast.

(3) The production value of traditional agriculture which is led by planting industry is still the main part of production of first industry. Stockbreeding and fishery develop quickly whereas the production value of forest industry grows tardily. So the government may put their main attention on the construction of planting and stockbreeding industry.

(4) The forest area increases gradually, and the forest cover rate increases as also. The forest cover rate may reach 78% at the end of the year 2020. This is the result of practice of cycle economy. The implement of cycle economy reduce the exploration of forest and make the material reused in the cycle of industries.

(5) Farming area decreases slowly. This may because of the area occupation of construction. Development of economy brings a lot of basic construction, so the occupation is ineluctable. But if the farming area decreases ceaselessly, it is not a nice phenomena. The government should take some measures to protect scanty farming area. The protect is a main part of cycle economy.

(6) The curve of water resource has the trend that decreasing firstly and then increasing. In 15 years, it will decrease but in the future time, it has an increasing trend. This is the result of the improvement of cycle utilization rate of waste water. The cycle utilization rate improved brings the decrement of utilization quantity of fresh water. So this is another result of cycle economy. The implement of cycle economy reduce the utilization of resources and gain much more economic benefit.

(7) The environment is greatly affected while the industry developing. The protection of environment is emphasized at the time of economy developing. We should advance the cycle utilization rate of water, protect the water resource, improve the comprehensive utilization rate of material, reduce the emission quantity of waste residue.

4 Conclusion

In this paper, we have established a new model called SD-FMOP that integrate system dynamic (SD) with fuzzy multi-objective programming. Cycle economy planning faces a huge and complex system in which the the precise value of variables and parameters are hard to obtain. SD and FMOP model can felicitously applied to conduct research on of the problems above, respectively. We can see that SD-FMOP describes the problem of cycle economy planning and is effective to optimize the system to get the sensitive parameters. Trough simulation and analysis, the course and the significance of cycle economy are clear. It may assist the government with the constitution of policies and statutes related to cycle economy scientifically. Though the new integrated model can solve such problems discussed in this paper, it is evident that the FMOP model only assist in modeling and getting some key variables. How to put the conception of fuzzy into all the system dynamic model is still a challenge to our work in the future.

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