On simulation and optimization of energy-saving textile industry system based on SD-SMOP model*

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Abstract. Industry planning is a complex decision making problem involving various criteria under dynamic situations. This paper studied the textile industry planning where textile industry is used to the one of most important national economical industry. We identify the main uncertain factors that affecting planning and then model and analyze them using random set, dynamic system and multiple objective programming theories. Thus, we develop system dynamic-stochastic multiple objective programming (SD-SMOP) models to plan and develop textile industry operations in this region. We then carry out a simulation experiment using optimized parameters from SD-SMOP. We compare performance from different models and show how decision-making is improved by the insight the model provides.

Keywords: simulation, optimization, textile, SD, MOP, energy-saving

1 Introduction

Textile is the one of most important national economical industry. In general, Chinese textile industry has gained relatively strong competitive advantage in the past twenty years. The plentiful natural resource, the abundant human resource pool and the increasingly domestic demand have provided substantial foundation for the development of textile industry. However, with the requirement of low-carbon development, coming of new economical development and growth of globalization progress, more and more serious circumstances need to be faced in the textile field: firstly, there are limitation of domestic resource, the problems of energy consumption, variation of consumption structure and level and some structure contradictions inherent in itself; secondly, there are challenges from complex international politics and economical trade environment. With the shrinkage of the international market demand, China’s textile industry must have to face many unprecedented pressures[1–3]. Therefore, it is more significant that how to formulate and implement development strategies, guide the textiles enterprises more positively and comprehensively to adapt to the requirement of low-carbon economy and participate in economic globalization trend, configure the industrial chain from the perspective of low-carbon development, cultivate strengths textile enterprises[4–6].

The city we have chosen has been one of the most representative cities on the textile industry in China and the only area sustained 20 years of spinning material and technologies’ research and production. From the past 20 years, this district have relied on industry cluster, adhered to the development of cotton-based non-agricultural industries, effectively promoting the aggregation and scale expansion of the industry, and transfer of rural labor. At present, weaving and spinning is dominant in this industry cluster, there are 88 textile enterprises, including 30 scale enterprises, 6000 looms, $12.5 \times 10^5$ ingots, $1.75 \times 10^5$ ton, annual output of cloth $140$ million meters, total assets 547 million yuan. 50 percent of fabric products is Exported directly or

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indirectly exported by trading companies, most products enter Jiangsu, Zhejiang, Guangdong, Chengdu and other textile market. Some products are exported to the United States, South Africa, India and other countries. The development of textile industry also can provide more jobs to this region’s rural labor force, achieve economic and social benefits.

2 Problems with current textile industry

Over the years, though the achievements of this district’s textile industry are notable, the ensued problems has become even more prominent:
(1) In recent years, the production growth slowdown and the effectiveness depressed. From 2006 to 2008, the Industrial value added of this region’s textile industry significantly slowed compared with previous years. The Industrial value added from 2006 to 2008 were respectively $5.4030 \times 10^5$ yuan, $5.4958.8 \times 10^5$ yuan, $6.0516 \times 10^5$ yuan, in 2007 only grew by 1.7% over 2006, and in 2008 than in 2007 also increased by only 10.1%, it’s much lesser than the growth rate of 26.5% of the region’s four dominant industries (electronics and polysilicon, textile, pharmaceutical chemicals, machinery casting).
(2) At present, this region’s textile enterprises are all limited to the stage of “spinning, weaving”, belong to the early processing of raw materials, at the low-end of the industrial structure and are labor-intensive production.

<table>
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<th>Table 1. Endogenous variables</th>
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product structure is single and additional value of products is low. In the absence of dyeing and finishing enterprises, the products are mainly dyed through the commission or directly exported to other provinces for further processing and export abroad. In addition, most production equipment is not advanced, and the level of technology is low, case only spinning, weaving enterprises of this region need spindles 600000 ingots per year, but the capacity of producing spindles in this region’s production zone is just 125000 ingots per year, that means, at least \( \frac{3}{4} \) spindles need to outsource every year.

(3) There are 88 textile enterprises in this region, including 24 scale enterprises, scale of key enterprises are generally small, and some companies are still in family workshop producing state, averagely annual output value of enterprises is less than 20 million yuan, compared with the developed textile industries in coastal areas, the production capacity of this region is lack of scale advantages.

(4) Climate change and its complexity and far-reaching implications which caused by energy consumption has changed the way of thinking of governments and enterprises. While energy prices continue rising, more and more large energy consumers, such as textile industry, has been forced to consider the problems of its cost control. For textile industry, it’s critical that how to efficiently use and manage energy. Primary energy consumption for the textile industry is coal and water, the energy consumption problems mainly concentrated in printing and dyeing industry and nearly 58% of the whole industry, the environmental pollution problems mainly concentrated in the emissions of wastewater, exhaust gas and heat generated in the process.

(5) Lack of innovative mechanisms, enterprises are not enthusiastic in Independent research and innovation. As scale of textile enterprises in this region are generally small, and subject to their own development and the lack of policy guidance, they serious lack of the enthusiasm in independent research and innovation of technologies and processes.

3 Modelling

We will now describe general SD-RMOP modeling. First, we explain the basic concepts of the stochastic variable and set up the universal form of the SD-SMOP model.

3.1 SD modelling

System dynamics (SD) is a science which is the close combination of system theory and computer simulation to research feedback structure and behavior of the system, and recognize system problems and resolve system problems, is an important branch of systems science and management science. Analysis the causality between factors within the system by research structural model of the system, and quantitatively analysis dynamic relationship between structure, function and behavior of the information feedback system by using of computer simulation technology, is a quantitative research method for the complex socio-economic system\([7–10]\).

SD has a particular emphasis on the behaviors and trends of a complex system. Simulation technology is only used to forecast the trends in the future years according to certain parameters and to reflect on the method, and thus cannot be used to estimate exact levels reliably\([11–13]\). Therefore, we also introduce multiple objective programming based on the SD to work through the random variables and get optimized results from the simulation.

3.2 SMOP modeling

Multi-objective programming(MOP) is to maximize (or minimize) many different objective functions under a set of constraints, this programming method is suitable for making decisions for the system involving two or more goals. However, many practical decision-making problems usually contains multiple incompatible goals, which often contradictory and constraints. Especially in industrial production under low-carbon development requirements, it is not only necessary to achieve high output and high efficiency, but also reduce energy consumption and carbon intensity\([14, 15]\).

As the influence of objective factors or human factors multi-objective decision often associated with many uncertainties. Thus parameter vector \( \omega \) which is not constant vector appears in the multi-objective planning
model. If the parameter $\omega$ is a random vector, then the corresponding problem is called stochastic multi-objective planning problem. Actually, since the emergence of random variables, the problem is no longer a mathematical programming problem in the strict sense. The sense of the maximize (or minimize) objective function $f_i(x, \omega), i = 1, 2, \cdots, n$ is not clear, and the constraints $g_j(x, \omega), r = 1, 2, \cdots, m$ also are not feasible region defined. So we need a further explanation for the meaning of the MOP, and the same problem also exists in the target problem with random coefficient.

4 Textile industry system

In this section, we will describe the textile industry system studied in our paper. The system is described diagrammatically in (see Fig. 1). We will define the parameters used to describe and analyze the system. We formed the parameter variables by studying textile industry chains and analyzing the flows of processing technique and show the results in (see Tab. 1). The settled values for the substance transforming rates, and some settled parameters in the system dynamic model are mainly based on: (1) the administration annual report for the region, (2) the programming reports on correlative industries, and (3) present market situation. The settled values were obtained via equilibration, linearity regression, index smoothness and other related mathematical models

$$
\begin{align*}
  y_i &= o_c \times x_i \\
  o_1 &= y_1 \times m_2 \times m_4 \\
  o_2 &= y_2 \times m_3 \\
  o_3 &= y_3 \times m_5 \\
  o_4 &= y_4 \times m_6 \times m_7 \\
  o_5 &= o_h \times m_9 \times m_{10} \\
  \frac{d\xi}{dx} &= p_i, i = 1, 2, \cdots, 5 \\
  \frac{dx}{dy} &= u_i, i = 1, 2, \cdots, 5 \\
  e_t &= e_1 + e_2 + e_3 + e_4 + e_5 \\
  v_t &= v_1 + v_2 + v_3 + v_4 + v_5 \\
  a_t &= (e_t/v_t) \times c_0 \\
  f_1 &= \sum_{i=1}^{5} \left[ p_i \tilde{s}_i - p_i o_i - h_i \times \max(o_i - \tilde{s}_i, 0) \right] \\
  f_2 &= \sum_{i=1}^{5} e_i
\end{align*}
$$

where $f_1$ is the gross profit and $f_2$ is the total energy consumption. The random variables $\tilde{s}_i, i = 1, 2, \cdots, 5$ respectively means the sales of leisure wear, dyeing cloth, industrial fabrics, jeans, home textile products. $x_i, i = 1, 2, \cdots, 5$ respectively means the weight of leisure wear, dyeing cloth, industrial fabrics, jeans, home textile products in cotton.

4.1 The optimizing formulas

As the model has random variables $\tilde{s}_i$ and unknown parameters $x_i$, we use stochastic multi-objective planning to realize the maximize of gross profit and the minimize of total energy consumption. The multi-objective planning of textile industry must reflect the different target values such as output, energy consumption and carbon intensity, interests of different production sectors, the relationship between production status of manufacturing sectors and energy consumption, and the relationship between demands for different products and so on.

Since we want to calculate the total profits of textile products, sales of all products is taken into account necessarily. However, based on statistical data, we can know that the sales of a product fluctuates in a certain range, therefore, we can assume that sales of products $s_i$ are random variables followed uniformly distribution.

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It follows from the expected operator that

\[
E[f_1(x, s)] = 250E[s_1] - 25702.08 \times 10^4 x_1 - 0.25E[\max(535.46 \times 10^4 x_1 - s_1, 0)] \\
+ 18E[s_2] - 2228.61 \times 10^4 x_2 - 0.17E[\max(825.41 \times 10^4 x_2 - s_2, 0)] \\
+ 13E[s_3] - 1739.87 \times 10^4 x_3 - 0.2E[\max(892.24 \times 10^4 x_3 - s_3, 0)] \\
+ 230E[s_4] - 19862.34 \times 10^4 x_4 - 0.25E[\max(575.72 \times 10^4 x_4 - s_4, 0)] \\
+ 96E[s_5] - 981.59 \times 10^4 x_5 - 0.28E[\max(68.17 \times 10^4 x_5 - s_5, 0)],\tag{2}
\]

\[
f_2(x) = 283.79 \times 10^4 x_1 + 288.89 \times 10^4 x_2 + 285.52 \times 10^4 x_3 + 322.4 \times 10^4 x_4 + 83.17 \times 10^4 x_5.	ag{3}
\]

Since the objective function \(f_1(x_i, s_i)\) includes some random variables, and decision makers usually want to the maximum expected profit, therefore, we need to compute \(E[f_1(x, s)]\). Taking \(\max\{c_1 x_1 - s_1, 0\}\) as an example to firstly show how to compute its expected value. Let \(s_1 \sim U(a_1, b_1)\) be a random variable subject to a normally distribution and it follows that \(E[\max\{c_1 x_1 - s_1, 0\}]\), \(a_1 \leq x_1 \leq b_1\), it follows that

\[
E = \left[\frac{1}{2}(c_1 x_1 - s_1 + |c_1 x_1 - s_1|)\right] = \frac{1}{2} \left[ (c_1 x_1 - a_1 + b_1) \right] = \frac{1}{2} \left[ \frac{(c_1 x_1 - a_1)^2 + (c_1 x_1 - b_1)^2}{2(b_1 - a_1)} \right]\tag{4}
\]

and by statistics we obtain (see Tab. 2).

Taking into account the actual demand for each products, production capacity of enterprises and constraints of resource and energy, we can get a series of corresponding constraints.

Thus, we can get the crisp objective function by the above formulas,

\[
\max F_1(x) = 346014.02 \times 10^4 - 716.79 \times 10^4 x_1^2 - 23876.52 \times 10^4 x_1 \\
- 1158.21 \times 10^4 x_2^2 + 80725.09 \times 10^4 x_2 \\
- 227.45 \times 10^4 x_3^2 + 172.07 \times 10^4 x_3 \\
- 138.11 \times 10^4 x_4^2 - 18325.08 \times 10^4 x_4 \\
- 32.53 \times 10^4 x_5^2 - 811.17 \times 10^4 x_5
\]

\[
\min F_2(x) = (283.79 x_1 + 288.89 x_2 + 285.52 x_3 + 322.4 x_4 + 83.17 x_5) \times 10^4
\]

\[
x_1 + x_2 + x_3 + x_4 + x_5 = 1
\]

\[
4125(x_1 + x_2 + x_3 + x_4) + 1500x_5 > 1600
\]

\[
373.41 x_1 + 288.89 x_2 + 285.52 x_3 + 377.4 x_4 + 297.04 x_5 < 1063
\]

\[
170 \leq 535.46 \leq 220
\]

\[
4800 \leq 892.24 x_2 \leq 5300
\]

\[
750 \leq 892.24 x_3 \leq 1100
\]

\[
800 \leq 575.72 x_4 \leq 1100
\]

\[
50 \leq 68.17 x_5 \leq 65
\]

\[
0 < x_i < 1, i = 1, 2, 3, 4, 5
\]

we solve the problem and the optimization results was given in Tab. 3.

| \text{Table 2. Values of } a_i \text{ and } b_i | \text{Table 3. Random variables} |
|---|---|---|---|---|---|
| \text{Variable} | \text{x}_1 | \text{x}_2 | \text{x}_3 | \text{x}_4 | \text{x}_5 |
| \text{Value} | 0.336 | 0.295 | 0.112 | 0.139 | 0.117 |

\begin{align*}
\begin{array}{c|c|c|c|c|c}
 a_i & 1 & 2 & 3 & 4 & 5 \\
\hline
170 & 4800 & 750 & 800 & 50 \\
220 & 5300 & 1100 & 1100 & 70 \\
\end{array}
\end{align*}

5 Optimization and simulation

According to the optimizing formulas and given solution methods we can obtain the optimum results \(x_i\) and \(f_i\) and compare them to the current scheme. We then inserted the parameter values into the system dynamics model. A system simulation was then performed using the simulation software VENSIM and marked.
the data from 2009 as the initial conditions, time=0. Time is measured in years. Our simulation spans 7 years, ranges from 1 to 7, and results in data analysis for year 2009 to year 2015. We depict the main pattern from (see Figs. 2, 3 and 4). (1) As a result of our scientific optimization techniques, there was a large increase in the economic growth and profits achieved by the textile industry. We can see that the total output values of the textile industry will reach 4 billion yuan (RMB) in 2015 based on the optimum scheme. More than the current scheme. Leisure wears and dyeing cloth will make the significant contributions to gross profit. While developing the advantages of labor resource, it’s necessary to Consolidate and improve the advantages of cotton yarn products. At the same time, it’s critical to develop apparel and textile industry, introducing of advanced production lines, establishing its own unified brand in the industrial clusters and adopting a unified sales network, besides, promoting the cooperation between the textile industry and ancillary services such as

**Fig. 1. Elements of low carbon tourism**

**Fig. 2. Elements of low carbon tourism**

**Fig. 3. Differential dynamic causality graph**

**Fig. 4. Differential dynamic causality graph**
logistics and e-commerce.

(2) By optimally allocating, elevating energy awareness in enterprises, introducing energy-saving technology and implementing waste water treatment technology, the growth rate of energy consumption is significantly reduced. In Fig. 4, we can see that the total energy consumption of the textile industry will be controlled in 12500 tons of standard coal in 2015 based on the optimum scheme, also the carbon emission intensity will be significantly reduced.

From the simulating figures above we have conclusion that using the optimization techniques and simulation forecasting we can efficiently estimate the developmental direction of the natural gas industry in this region. The results will assist administration to establish policies that more effectively promoting further growth and development than an unguided analysis [16–18].

6 Conclusion

In this paper, we have developed a model that integrates system dynamics-stochastic multi-objective programming (SD-SMOP). This model can be used to study the complex interactions in a textile industry system. In the process of confirming random variables of the SD model, we made use of stochastic multi-objective programming to help yield the solution. It is evident that SMOP is effective in optimizing the given system to obtain the decision objectives of the SD model. The results recorded from the SD model are in our option, reasonable and credible. While our integrative model used to study textile industry systems planning is helpful in, other areas and problems remain. The next phase of our work is to set up a general system-dynamical optimization model incorporating and testing various solution methods.

References


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are for the variation of loads between 1.8

C = 42.37 micro F

Clo = 300 micro F

u = 1 p.u

p.f = 1

are depicted

C = 92.3 micro F

Clo = 300 micro F

u = 1 p.u

p.f = 0.9 lag

\( X \) is observed that the time taken using PSO method is very less as compared to the NR method. The values
carried out with this method in similar way.

involving calculations of partial differential equations and Jacobian matrix. Sometimes, calculation of Jacobian
matrix is not possible if the matrix is symmetrical. Also the calculation of Jacobian matrix becomes cumber-
some and time consuming as the number of variables and size of the Jacobian increases. Even to calculate
unknown parameters \( X_C \) and \( F \) to maintain the constant terminal case, there is no need to formulate the equations
once again in PSO method, and the analysis of SEIG with short shunt and/or long shunt can be easily
carried out with this method in similar way.

5.4 With long-shunt compensation

The steady state performance of long-shunt single phase SEIG is studied with \( upf \) and 0.9 \( pf \) load as
shown in Figs. 19~22. In long-shunt configuration, the short-shunt component \( X_{csh/F} \) is neglected in z9. To
find unknown values of \( X_M \) and \( F \), the Eq. (9) is again solved by including the \( X_{clo/F} \) in z9. With long-shunt
compensation, it is observed that the voltage regulation with reactive load is better as compared to short-shunt.
A comparative study of the results with PSO method and those are obtained with NR method[9] are depicted in
Tab. 3.

From the Tab. 3, it is evident that the proposed method is efficient and robust. The results presented in
Tab. 3 are for the variation of loads between 1.8 \( \Omega \) and 40 \( \Omega \), for \( X_C = 1.516 \ p.u \) (56 \( \mu F \)) and \( v = 1 \ p.u \). It is
observed that the time taken using PSO method is very less as compared to the NR method. The values \( X_M \)
and \( F \) obtained using above are used to compute the performance of the single phase single winding SEIG
under various conditions. Close agreement between the results obtained using two methods are observed. The
main advantage of this method is that, there is no need of any initial guess values, which highly affects the
performance and convergence criterion of the NR method.

Some times, wrong initial guesses in NR method will cause the divergence of the solution. The other
advantage over NR method is that the proposed PSO method does not requires any tedious manual work in-
volving calculations of partial differential equations and Jacobian matrix. Sometimes, calculation of Jacobian
matrix is not possible if the matrix is symmetrical. Also the calculation of Jacobian matrix becomes cumber-
some and time consuming as the number of variables and size of the Jacobian increases. Even to calculate
unknown parameters \( X_C \) and \( F \) to maintain the constant terminal case, there is no need to formulate the equations
once again in PSO method, and the analysis of SEIG with short shunt and/or long shunt can be easily
carried out with this method in similar way.
6 Conclusion

The steady state performance of single phase single winding SEIG based on branch impedance method using graph theory (tie-set) and PSO with different compensation under various operating conditions has investigated in this paper. The effectiveness of additional series capacitance to provide additional VAR with load to improve and maintain constant terminal voltage and output power is presented. It is observed that similar characteristics obtained in both short and long shunt configuration. Thus, the investigation suggests a workable model of single phase single winding SEIG using PSO which is simple, rugged and stand alone self regulated capacity. Based on closed agreement between the results using NR method and PSO method at different loads, it can be concluded that the approach made in mathematical analysis is elegant.

References


Appendix

The machine has the following particulars: Single-phase, 4-ploe, 50 Hz, 225 V, 6 A, 750 W, 1500 rpm capacitor start Induction machine.

\[
\text{Base voltage/current } = 225V/6A, \text{ base power } = 1350W, \text{ } R_m = 2.812\Omega, \\
R_r = 3.973\Omega, X_{lm} = X_{lr} = 6.410\Omega, \text{ } v = 1\text{ p.u, Load } = 33.75W - 750W.
\]

The relationship between \( X_M \) and \( V_g/F \) is given by:

\[
V_g/F = 1.689 - 0.2X_M \text{ (for } X_M < 3.2\text{ p.u) and } V_g/F = 2.844 - 0.55X_M \text{ (for } X_M > 3.2\text{ p.u).}
\]