SD Model Research on Science and Technology Resource Input and Output in Towns of Industry Clusters

Jian-wen HE*
Guangdong Institute of Scientific & Technical Information, Guangzhou 510033, China
*Corresponding author

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Abstract. Based on the system dynamics (SD) principle aspect, this text built up the mathematics model on the input and output of science and technology (S&T) resource in towns of industry clusters(TICs), used the Simulink of MATLAB to set up the homologous calculator model to imitate the real situation, and finally got the emulation result about the future development condition of S&T resource input and output in TICs. Through the deep analysis on the emulation result, this text also provided some practical, feasible and scientific basis for the design on the sustainable development of S&T resource input and output and the upgrading of TICs.

Introduction

At present, China has entered a critical period of development and urbanization driven by innovation, and towns of industry clusters (TICs) have played an extremely important role in this critical period. Take Guangdong as an example: the authorized amount of patent in the TICs accounts for 40% of the whole province, which contributes more than 1/3 to the GDP of the whole province. This is mainly due to the potential accumulation of science and technology(S&T) resources in the town and the innovation effect of S&T brand construction [1]. The sustainable growth of the input and output of S&T resources has important strategic significance in the development model of the TICs. Therefore, it is a valuable research topic to make a systematic analysis of the components, influencing factors and factors of the input and output of S&T resources of TICs, to accurately grasp the overall structure and various dynamic feedback mechanisms of the input-output system of S&T resources, and to obtain the reliable prediction results of the input and output of S&T resources. As the System Dynamic (SD) is a research method to deconstruct the social dynamic complex system [2]; not only has a complete modeling tool, but also has a complete theoretical system and methodological significance, this paper tries to simulate and analyze by establishing a SD model to explore the development trend of input-output situation of S&T resources in the TICs, find out the possible problems and related constraints in the future development process, and put forward corresponding suggestions and countermeasures.

Concept Definition

Similar researches on TICs abroad are mainly embodied in industrial cluster theory. The industrial cluster was first proposed by the famous British economist Marshall in 1890. He believed that the industrial cluster was the product of the production activities and the product of the division of labor [3]. Weber further pointed out that industrial clusters are interrelated enterprises in order to save operating costs and tend to concentrate on location adjustment[4]. In 1990s, domestic scholars raised and paid attention to TICs. Jun WANG pointed out that the TICs is the construction of the towns based on a highly specialized production and industrial agglomeration [5]; Jing SHEN, etc., believed that the TICs refers to the specialized production of one or two industries in a town domain, and forms a specialized township economic development and employment pattern with a certain scale as the main township economic form [6]. Therefore, this article holds that the TICs is a spatial economic form which is formed on the basis of the specialization, technology and scale of production, which is formed by market competition and government guidance to strengthen and
concentrate production elements gradually to the most economic advantages of local products and production links.

On the definition of S&T resources, the theoretical circle has not reached a consensus, which is more representative: Han-lin LI believed that S&T resources are all the resources that direct or indirectly promote the progress of S&T to promote economic development, including the general sense of labor, scientific research personnel, funds, the stock of S&T, the environment and so on. Wei ZHAO, etc., pointed out that S&T resource is a system composed of these factors and their secondary factors, including soft and hardware elements, which could interact with each other. Therefore, this paper argues that S&T resources refer to the material or spiritual wealth elements and essential factors that can promote economic and technological development. As for the internal problems of S&T resources, scholars hold different views: Ji-zhong ZHOU believed that most of the factors such as S&T information resources, S&T material resources and S&T organizations resources are mostly reflected in the human resources of S&T and the financial resources of S&T, and these two are of relative importance and decisive significance. Jian-guo XU further pointed out that the human, material and financial resources of S&T are the core of the S&T resources, which is more accurate than the analysis results obtained by the use of human and financial indicators as the index of S&T resources. To sum up, this paper tries to measure the S&T resources from 3 aspects: S&T manpower, financial resources and material resources.

Construction of Mathematical Simulation Model

According to the definition mentioned above, this paper holds that the main components of the input and output model of TICs S&T resources are the number of S&T personnel, the investment in S&T and the amount of patent authorization in the whole society. Therefore, this paper first simplifies the factors of the input-output system of TICs S&T resources into three parts: the number of S&T personnel (input subsystem), the whole social S&T input (input subsystem) and the patent authorization quantity (output subsystem); at the same time, the main causes of the changes of the 3 variables are further found, and divided into endogenous variables (the S&T input of the whole society of every S&T personnel, the average realization of the patent output of every total social S&T input, and the average realization of the patent output by every S&T personnel, for short, the per capita investment in S&T, the patent output rate, the per capita patent output) and the exogenous variable (TICs). The total value of regional production, the S&T input of the town government, the number of high-tech enterprises in the town, and the principle of system dynamics are used to describe the causal relationship diagram between these variables. Finally, on the basis of constructing the mathematical model, the corresponding computer simulation model is established by using the Simulink tool in the mathematical software MATLAB.

Determining Variable Factors and their Relation

The purpose of this system is to explore the relationship between these variables and future changes. In order to ensure the availability and validity of the index data, it is assumed that the influence of environment and geographical location on the model is minimal or not affected. This paper draws a dynamic causality diagram of the input-output system of S&T resources in TICs (see Figures 1, 2).
Operationalized Definitions of Variables

The operational definition of the system variables is as follows: (1) the number of scientific and technological personnel called $x= \text{the number from high-tech enterprises} + \text{the number from non-high-tech enterprises}$; (2) the whole social science and technology input in the town called $y= \text{S&T investment from enterprises in the towns} + \text{S&T input from the town government} + \text{S&T input from other economic owners in the towns}$; (3) the patent authorization amount called $z= \text{the amount of patent authorization from high and new technology enterprises} + \text{the amount of patent authorization from non-high and new technology enterprises}$; (4) per capita investment in S&T called $r_1 = y / x$; (5) patent output rate called $r_2 = z / y$; (6) per capita patent output called $r_3 = z / x$; (7) the annual variation of $x$ called $\frac{dx}{dt} = \text{the annual increases} - \text{the annual decreases}$; (8) the annual variation of $y$ called $\frac{dy}{dt} = \text{the annual increases} - \text{the annual decreases}$; (9) the annual variation of $z$ called $\frac{dz}{dt} = \text{Newly authorized volume of patents in the year}$; (10) $g$ for GDP of the towns; (11) $s_g$ for the town government investment in science and technology; (12) $m_z$ is the number of high-tech enterprises in the towns.

Mathematical Model Construction

From the historical data, we can see that the number of scientific and technical personnel in the TICs, the total social S&T input and the total number of three variables of the patent authorization are increasing exponentially. By calculating the first order difference ratio, the first order difference ratio of the three can be found to be in accordance with the digital characteristics of the exponential curve model. Therefore, this paper uses the exponential trend extrapolation method, assuming that the growth of the three variables is not related to each other, and is not affected by the external conditions, then the corresponding model is established. Since the model is derived from both sides of the model, the formula (1) can be obtained. In formula (1), $a$ is the annual (relative) growth rate of the number of S&T personnel; $b$ is the annual (relative) growth rate of the whole social S&T input of the town; $c$ is the annual (relative) growth rate of the amount of patent authorization. In fact, formula (1) is only a theoretical level. According to the causality diagram, the annual changes of the number of S&T personnel, the total social S&T input and the amount of patent authorization of the three are affected by the per capita investment in S&T, the rate of patent output, the per capita output of patent, the gross product of the TICs area, the investment in the town government and the number of high-tech enterprises in the town. Therefore, $a$, $b$ and $c$ can be used as the three functions taking these factors as independent variables, the formula (1) is variable to formula (2). In formula (2), $K$ is the patent review cycle (year). The cycle of patent examination is mainly influenced by the subjective role of the examiner and the adjustment of the country's policy. Therefore, this paper considers that the patent average review cycle, $K$, is regarded as a constant only by the influence of the external causes of the system, and is determined to be 2 in combination with the actual situation of the domestic patent examination.

\[
\begin{align*}
  x &= C_1 e^{ax} \\
  y &= C_2 e^{by} \\
  z &= C_3 e^{cz} \\
  \frac{dx}{dt} &= ax \\
  \frac{dy}{dt} &= by \\
  \frac{dz}{dt} &= cz
\end{align*}
\]

\[
\begin{align*}
  \frac{dx}{dt} &= a(r_1, r_2, g, s_g, m_z)x \\
  \frac{dy}{dt} &= b(r_1, r_2, g, s_g, m_z)y \\
  \frac{dz}{dt} &= c(r_1, r_2, g, s_g, m_z)z + \frac{z}{K}
\end{align*}
\]

\[\cdots(1)\]

\[\cdots(2)\]

Assuming that all three growth functions are linear, the formula (3) can be obtained. As $r_1 = y / x$, $r_2 = z / y$, $r_3 = z / x$, the formula (4) can be further derived.
This nonlinear differential dynamic system equations is a mathematical model of the input and output system of specialized S&T resources. Among them, equation (4-1) represents the subsystem of the S&T personnel; the equation (4-2) represents the subsystem of the whole social S&T input; the equation (4-3) represents the patent authorization quantum system.

**Computer Simulation Application**

**Parameter Estimation**

In view of the typical demonstration role of Guangdong in the construction of TICs and special towns in China, this paper will use the annual survey data of Guangdong TICs to simulate and analyze the status of the input-output system of TICs' S&T resources. The relevant data are from the Guangdong statistical yearbook, the Guangdong S&T Statistics Yearbook and the S&T statistics of Guangdong province. The time span of the data is from 2007 to 2016 (10 years). Data need to be processed without Dimensionalization. Before the simulation analysis, the multivariate linear regression statistical method is used to estimate the parameters of the related model. The statistical analysis tool used is SPSS 17, and the relevant analysis results are given here.

Firstly, parameter estimation and hypothesis test on \( a = a_0 + a_1 r_1 + a_2 r_2 + a_3 g + a_4 s_g + a_5 m_z \) are carried out by multiple linear regression method. As \( \frac{dx}{dt} = ax \), thus \( a = \frac{dx/dt}{x} \), so \( a = \frac{\Delta x}{x} \), while \( \Delta x = x_{i+1} - x_i \), \( \bar{x} = \frac{x_1 + x_{i+1}}{2} \) (i=0,1,2,…, 9). The results are as follows:

1. The gradual entry method is used as the introduction of variables in this test.
2. Regression equation F test: \( F=2.874, \ p=0.139<0.15 \), that is, the linear regression relationship between dependent variable and independent variable is partially significant.
3. The determination coefficient \( R^2=0.697 \) indicates that the fitting degree of sample data is high.
4. The result of regression coefficient T test is shown in Table 1. The test shows that the relationship between variables \( r_3, g \) and \( a \) is not significant. Variables \( r_1, \ s_g \) and \( m_z \) can explain the change of \( a \) very well, so \( a \) is interpreted by \( r_1, \ s_g \) and \( m_z \).

As the same as above, the results about \( b=b_0 + b_1 r_1 + b_2 r_2 + b_3 g + b_4 s_g + b_5 m_z \) are as follows:

1. The gradual entry method is used as the introduction of variables in this test.
2. Regression equation F test: \( F=3.291, \ p=0.098<0.10 \), that is, the linear regression relationship between dependent variable and independent variable is partially significant.
3. The coefficient of determination \( R^2=0.564 \), which indicates that the fitting degree of sample data is high.

As the same as above, the results about \( c=c_0 + c_2 r_2 + c_3 r_3 + c_4 g + c_5 s_g + c_6 m_z \) are as follows:

1. The gradual entry method is used as the introduction of variables in this test.
(2) Regression equation F test: F=6.076, p=0.037<0.05, that is, the linear regression relationship between dependent variable and independent variable is significant.

(3) The determination coefficient $R^2=0.829$ indicates that the sample data have a extremely high fitting degree.

(4) The result of regression coefficient T test is shown in Table 1. The test shows that the relationship between variable $r_2$, $m_2$ and $c$ is not significant, and the variable $r_3$, $g$ and $s_g$ can explain the change of variable $c$ very well, so $c$ is explained by $r_3$, $g$, $s_g$.

Table 1. T Test results of regression coefficient.

| B   | a1  | a2  | a3  | a4  | a5  | a6  | b1  | b2  | b3  | b4  | b5  | b6  | c2  | c3  | c4  | c5  | c6  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Sig | 0.054 | 0.203 | 0.730 | 0.089 | 0.043 | 0.038 | 0.673 | 0.969 | 0.821 | 0.053 | 0.249 | 0.034 | 0.013 | 0.021 | 0.914 |

Table Note: If Sig is less than 0.10, * will be marked; If Sig is less than 0.05, ** will be marked.

**Computer Simulation Model--the Application of Simulink**

In view of the wide and complex structure of this model, the model system is first divided into three subsystems: SubsystemX (the number of S&T personnel), SubsystemY (the whole social S&T input) and SubsystemZ (the patent authorization), and the corresponding simulation submodels are set up. Finally, they are encapsulated into a general system (see figure 3-1). The process of computer simulation needs to use the differential equations of type (4). The Simulink commands involved mainly include: In, Out, Add, Product, Divide, Integrator, Math function, Gain, Scope, Subsystem and so on. In addition, before the computer simulation model is run, each parameter should be put into the workspace and the corresponding M file is run. During the operation of the simulation model, the parameters of the workspace will be automatically invoked. If the subsystem of the above model system is deconstructed, figure 3-2 can be obtained.

**Result Analysis and Test**

The relative error of most simulation values and historical values of this model is not more than 5%, and the simulation curves are basically consistent with the actual data points (as shown in Figure 4, Figure 5, Figure 6), so the model has passed the historical simulation test. The results of the simulation and prediction show that the total social S&T investment and the amount of patent authorization will maintain a rapid growth momentum, and the number of scientific and technical personnel will show a relatively slow linear trend in the future period, which is in line with the actual development of the TICs in recent years (Figure 7, Figure 8, Figure 9). It is obvious that the
system boundary and parameter values of the model are reasonable and practical, so the model’s overall behavior pattern is basically consistent with the theoretical deduction and empirical judgment, and the model has passed the theoretical test. To sum up, this model can effectively represent the system proposed in this paper and describe the reality, which can be used for simulation and prediction.

(Figure Note: The vertical axis units of Figure 4 and Figure 7 are all ten thousand people; the vertical axis units of Figure 5 and figure 8 are all ten thousand yuan; the vertical axis units of Figure 6 and Figure 9 are all parts; the horizontal axis units of Figure 4 to figure 9 are all year.)

Figure 4, 5, 6. Comparison between Simulation Curves and Actual Data Points: the Number of S&T Personnel, the Whole Social S&T Input in the Towns, Patent Authorization Amount.

Figure 7, 8, 9. Simulation Prediction Curves: the Number of S&T Personnel, the Whole Social S&T Input in the Towns, Patent Authorization Amount.

Simulation Analysis of Input and Output System of S&T Resources in TICs

Current Assessment of the Growth Rate of Each Factor

According to the result of parameter estimation, the growth rate equation of variable x is determined as 
\[ x = a_0 + a_1 r + a_2 s + a_3 m, \]
and the estimated values of each parameter are: 
\[ a_0 = -3.572, \quad a_1 = 9.726, \quad a_2 = 5.365, \quad a_3 = 3.042. \]
Therefore, x is mainly affected by per capita investment in S&T, and the number of high-tech enterprises in the towns, while per capita investment in S&T has a greater impact, and the number of high-tech enterprises in the towns has a smaller impact.

The growth rate equation of variable y is determined as 
\[ y = b_0 + b_1 r + b_2 m, \]
and the estimated values of each parameter are: 
\[ b_0 = -4.324, \quad b_1 = 9.136, \quad b_2 = 3.813. \]
Therefore, y is mainly affected by per capita investment in S&T, and the number of high-tech enterprises in the towns, while per capita investment in S&T has a greater impact, and the number of high-tech enterprises in the towns has a smaller impact.

The growth rate equation of variable z is determined as 
\[ z = c_0 + c_1 r + c_2 g + c_3 s, \]
and the estimated values of each parameter are: 
\[ c_0 = -2.607, \quad c_1 = 13.257, \quad c_2 = 27.917, \quad c_3 = 21.402. \]
Therefore, z is mainly affected by per capita patent output, GDP of the towns, the town government investment in S&T, while GDP of the towns has a greater impact, per capita patent output has a smaller impact.
Predictive Analysis of the Change of Each Factor

**The Number of S&T Personnel.** From 2009 to 2015, the number of professionals in TICs has maintained a relatively rapid growth. This is mainly due to the continuous progress of the global technological revolution and industrial transformation, and the number of S&T enterprises and the number of R & D personnel has been increasing rapidly. With the improvement of social labor productivity, people's education level has been generally improved, which makes more and more people have the ability to engage in S&T work. At the same time, under the guidance of the government, the whole society's investment in S&T has been continuously strengthened, and it has laid a material foundation for people to engage in S&T work. Therefore, in the next 2017-2020, the number of professionals in TICs will continue to grow rapidly.

**The Whole Social S&T Input in the Towns.** The whole town social S&T input has achieved rapid growth in 2009-2014, and the annual growth rate has been close to 50%. In the past 2015-2016, domestic economic growth has entered a new normal. This has prompted a marked slowdown in the growth of S&T investment of the whole society in TICs. It is estimated that by 2020, the total social S&T input in TICs will be roughly stable at around 50 billion yuan. This may be because the S&T enterprises of the TICs have the same life cycle. After the growth stage and the mature stage, it will enter the stagnant stage or the recession stage, which makes the development of the TICs S&T industry turn to slow, and the investment enthusiasm of the whole society is also reduced accordingly.

**Patent Authorization Amount.** In the 2009-2015, the amount of patent authorization of TICs has reached an important stage in the growth of large fluctuations. In the “13th Five-Year” period, the growth of patent license slowed down, but still maintained a high growth rate: according to the simulation curve, from 2017 to 2025, although the number of S&T personnel will maintain steady growth, the growth rate of the patent license of the TICs may be higher than the growth rate of the number of S&T personnel. Therefore, in this period, the relevant functional departments of the government should pay attention to prevent and stop the appearance of patent application fraud and patent examination without strictness, so as to ensure the quality and benefit of the production of the S&T resources of the TICs.

**Conclusion and Prospect**

In this paper, in the process of analyzing the input-output system of TICs' S&T resources, the method is novel and unique, and the Simulink function of the engineering simulation software Matlab is used to simulate the input-output status of S&T. This is the innovation of this paper. By drawing the Dynamic Causality Diagram of the TICs' S&T resources input-output system, this paper sets up a mathematical model of the systematic research on the input-output of S&T resources of the TICs, and on the basis of this, realizes the construction of the computer simulation system, and obtains the trend curve of the future development of the input and output status of the TICs S&T resources. The blueprint for the development prospect of S&T resources in TICs is depicted. The results of relevant simulation analysis can provide reference for the government to formulate relevant policies. This has a positive guiding significance for further speeding up the transformation and upgrading of TICs during the 13th Five-Year and promoting the accelerated development of urban economy and society.

The following research in this paper can be focused on the following aspects: in a sense, any model is simplified to a certain degree of the actual system, and this model is no exception. If the model system of this article is closer to the objective reality, the ecological environment system of the TICs and the industrialization of S&T achievements are considered. What will be the conclusion when these are included in the model system of this paper?
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