Diffusion Behavior and Analysis of the Green Manufacturing Mode under the Influence of Government

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***Abstract*—This paper deals with the competition diffusion model of the green manufacturing mode, as well as parameter analysis and identification of the model. The aim is to better reveal the diffusion rules of the green manufacturing and provide a new quantitative way to diffusion study on advanced manufacturing modes. First, considering the diffusion characteristics of the green manufacturing mode, the competition diffusion model of the green manufacturing mode is established. Second, the model is analyzed, and qualitative results are presented. Government influence parameter is analyzed to reveal its influence on the diffusion process. Third, based on a practical application of the diffusion model, a parameter identification model is proposed. A parameter identification algorithm based on genetic algorithm (GA) is proposed to obtain optimized parameters for the diffusion model. The resulting model output is compared and contrasted with real data. Finally, the application of the model is explained. The proposed model and algorithm disclose the diffusion rules of the advanced manufacturing modes, and provide a new approach to the identification of parameters in the diffusion model. This helps to understand the diffusion status of advanced manufacturing modes and provides a decision-making basis for enterprises and governments.**

***Index* competition diffusion, decision support, Green manufacturing mode, parameter identification, genetic algorithm**

I. INTRODUCTION

The manufacturing industry is the strategic industries of a country [1], and it not only reflects productivity level and defense capabilities, but also determines the competitiveness and overall strength of a country. Therefore, the development of the manufacturing becomes an opportunity for economic growth. At present, with dynamic information, the changing market, as well as the deepening of competition and cooperation, international manufacturing mode is undergoing major changes. Governments of the United States, Britain and other industrialized countries have introduced the national manufacturing strategies in the new environment, so as to promote the development of advanced manufacturing. Unfortunately, though China has become a big manufacturing country in the world, manufacturing in China, especially the metallurgical industry, is high energy consumption, high pollution and low added value, low labor productivity development and faces with growth limits. According to statistics, energy utilization efficiency in China is lower than that of developed countries by nearly 10% [2], and natural resource consumption ratio is about 100 times that of Japan, France and South Korea, industrial waste density is about 20 times that of Germany, 18 times of Italy, South Korea and the 12 times of United Kingdom. If the manufacturing mode is not effectively transformed, the energy supply will limit the further growth of the manufacturing industry, and the ecological environment will also be difficult to support the continued development of the manufacturing. Therefore, it is inevitable to implement green manufacturing mode so as to realize sustainable development.

Implementation of the green manufacturing mode has become an inevitable trend of the manufacturing industry. It involves the acceptance, adaptation, and application (collectively, the diffusion process) of the green manufacturing concepts, technologies and system, and in this process, there are competitive relationships among different modes. Since the introduction of the concept of the green manufacturing in 1990s, studies of the green manufacturing have focused on the following aspects: (1) the concept and connotation of the green manufacturing. (2) technologies and processes of the green manufacturing. (3) applied research of the green manufacturing. (4) evaluation of the green manufacturing system. As an example of (1), reference [3] studied the strategies of sustainable development on the basis of a proposed preliminary framework for the green manufacturing. As an example of (2), reference [4] analyzed the various stages of green manufacturing technologies as well as the implementation of green manufacturing technology program. As an example of (3), reference [5] analyzed the key factors of the green manufacturing in iron and steel enterprises in China, and proposed the architecture of the green manufacture in iron and steel enterprises. As an example of (4), reference [6] proposed principles, methods for green manufacturing index system, and built the general index system of the

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green manufacturing system. Although the concept, technologies, application and evaluation of the green manufacturing have been extensively studied, little literature has focused on the mechanisms of the green manufacturing mode diffusion, and studies remain in the conceptual analysis and qualitative level. Reference [7] studied the acceptance process of an advanced manufacturing system for the first time, but only gives a simple diffusion model, and did not consider the ability of enterprises and competition. So far, the green manufacturing diffusion model is rarely involved based on its diffusion mechanism.

The diffusion process of the advanced manufacturing mode is the competition diffusion process, and in the process, the enterprise's ability directly determines the implementation of the mode. Therefore, as a kind of advanced manufacturing modes, it is necessary to consider green manufacturing competitive diffusion behavior considering the enterprise ability, so as to further clarify the diffusion rules of the green manufacturing mode. The diffusion characteristics of the green manufacturing are analyzed, and a competitive diffusion model is established, and then the competitive diffusion model is discussed. Finally, parameter identification method based on genetic algorithm is proposed to obtain the optimized values. This can help enterprises and governments to better understand the law of the advanced manufacturing mode diffusion, so as to more accurately predict the future implementation and development of the advanced manufacturing mode, in the meantime, provide a quantitative theoretical basis for rational decision-making of enterprises and governments.

II. Diffusion Model of the Green Manufacturing Mode

A. *Influencing Factors of the Green Manufacturing Mode Diffusion*

As a kind of advanced manufacturing modes, the diffusion of green manufacturing is influenced by many factors, which can be analyzed by dynamic system method as shown in Fig.1.

The influencing factors of the green manufacturing mode diffusion include: enterprise requirement, pressure from competitors, implementation risk, superiority of the mode, match degree between enterprise culture and the mode, government tax revenue support, credit ability, financial status, human resource, enterprise scale, organization structure. Meanwhile government tax revenue support, credit ability, financial status, human resource, enterprise scale, organization structure have impact on the enterprise's ability to implement the green manufacturing mode.

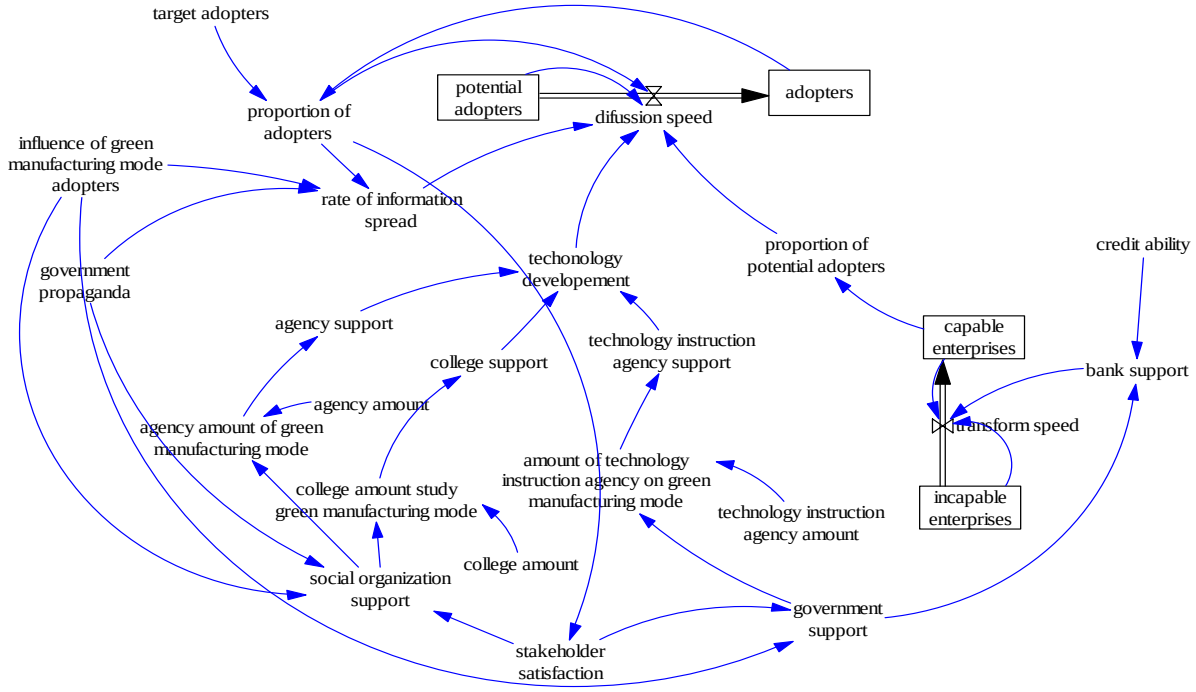

Figure.1 System dynamics analysis of the green manufacturing diffusion

B. *Diffusion Characteristics of the Green Manufacturing Mode*

The implementation of the green manufacturing system involves the acceptance, adaptation, and application (collectively, the diffusion process) of the green manufacturing mode, which is different from the product diffusion and technology diffusion [8-11]. The diffusion characteristics of the green manufacturing mode are as follows:

H1. The green manufacturing mode can be developed and improved with technologies. Thus, it has substitutes.

H2. In a given period, the number of enterprises is finite: that is, the number is a constant.

H3. In reality, all enterprises have some information about the green manufacturing mode.

H4. Because of competition in the market, all enterprises are willing to implement green manufacturing mode.

H5. Government support is an important outer factor promoting the implementation of the green manufacturing mode.

The influencing factors can be divided into outer environment factors, inner factors, enterprise factors and technological status factors. And the factors can be classified into two categories: (1) enterprises' capacity, and (2) their willingness. Therefore, according to the capacity and willingness of enterprises, enterprises are divided into four kinds.

(1) x_1 , enterprises that have the capacity to implement the green manufacturing mode, and are yet to do so.

(2) x_2 , enterprises that do not have the capacity to implement mode, but are yet to do so.

(3) y_1, enterprises that have already implemented the green manufacturing mode.

(4) y_2 , enterprises that have already implemented the competitive mode.

C. Competition Diffusion Model of Green Manufacturing Mode

According to H2, $x_1 + x_2 + y_1 + y_2 = m$, where m is the potential number of enterprises. In a given period, the competition diffusion model is as follows:

$$\begin{cases} \dfrac{dx_1}{dt} = -\lambda x_1 - (p_1 + q_{11}\dfrac{am - x_1}{am})x_1 - (p_2 + q_{12}\dfrac{am - x_1}{am})x_1 \\ \dfrac{dx_2}{dt} = \lambda x_1 - (p_2 + gq_{21}\dfrac{bm - x_2}{bm})x_2 - (p_2 + gq_{22}\dfrac{bm - x_2}{bm})x_2 \\ \dfrac{dy_1}{dt} = (p_1 + q_{11}\dfrac{am - x_1}{am})x_1 + (p_1 + gq_{21}\dfrac{bm - x_2}{bm})x_2 - \theta y_1 \\ \dfrac{dy_2}{dt} = (p_2 + q_{12}\dfrac{am - x_1}{am})x_1 + (p_2 + gq_{22}\dfrac{bm - x_2}{bm})x_2 + \theta y_1 \end{cases} \quad (1)$$

where, λ is competition transferring coefficient from x_1 to x_2, p_k is the influencing coefficient to potential adopters to implement the mode k , q_{11}, q_{12} are inherent diffusion rates of x_1 to y_1 and y_2, q_{21}, q_{22} are inherent diffusion rates of x_2 to y_1 and y_2 . θ is competition transferring coefficient from y_1 to y_2. g is government coefficient to potential adopters.

In reality, the diffusion of the green manufacturing mode is a process with limited rationality. Under the influence of current adopters, the government, and the external environment, potential enterprises (those that have not implemented the green manufacturing mode) may transfer to different advanced manufacturing modes. Also, if one mode has advantages over the others, those using the first mode may transfer to the more advanced mode.

D. Analysis of the Diffusion Model

Eq. (1), is an autonomous system, which can be analyzed through Lyapunov stability, and the following conclusions can be obtained.

Theorem 1. When $\theta = 0$, the diffusion model represented by Eq. (1) has the form of Bass model.

Theorem 2. When $\theta = 0$, $p\ (0,0,m - y_2, y_2)$ is the balanced point of system (1). Furthermore, when $t \to +\infty, \lim_{t\to+\infty} x_1(t) = 0, \lim_{t\to+\infty} x_2(t) = 0$, and $y_1 + y_2 = m$.

According to Theorem 2, when $t \to +\infty$, the transformation is completed, and enterprises implementing two modes will be balanced. This means that the green manufacturing mode and its competitive mode commonly possess the market, and the market share depends on the initial value and their inherent diffusion parameters.

III. Simulation and Analysis of the Diffusion Model

A. Relative Data of the Diffusion Model

To show the application of the competition diffusion model of green manufacturing mode, green manufacturing is denoted as mode A, and can be measured by enterprises that have received Chinese environment mark certification. Total quality management is denoted as mode B, and can be measured by enterprises that have received ISO9001 quality accreditation. Data for these modes can be obtained through many methods such as investigation, statistical data, and the evaluation of statistical data. Related data are shown in Table 1.

TABLE1
NUMBER OF ENTERPRISES IMPLEMENTING MODES

Time / Mode	2005	2006	2007	2008	2009	2010
A	328	335	704	1180	1340	1742
B	1000	1238	1771	2139	2405	2617

From the above background [12], the initial time of the system (1) is set to 2005. From the 2006 China Industrial Economy Statistical Yearbook[13], the number of enterprises with the potential to implement advanced manufacturing modes was found to be $m = 29774$. The ratio of large enterprises and medium enterprises in 2005 was $a = 0.08$, $b = 0.92$, respectively. The ratio of enterprises that go bankrupt each year in large and medium enterprises was $\beta = 0.12$. There are many ways to evaluate q of the diffusion model. Rogers (1995) concludes that the even value of the inner diffusion factor is 0.38. q can be obtained by method such as nonlinear least square estimation according to statistical data . For quantitative results, other parameters of system (1) are

given in Table 2. For quantitative results, other parameters of system (1) are given as shown in Table 2.

According to Eq. (1) and the parameters in Table 2, $x_1(t)$, $x_2(t)$, $y_1(t)$, and $y_2(t)$ can be obtained from the initial time $t(0)$. Matlab 7.1 was used to simulate the diffusion model, and the simulation results are shown as follows. For clarification of these results, with t as an independent variable, the variations of $x_1(t)$, $x_2(t)$, $y_1(t)$, and $y_2(t)$ are shown in Fig. 2.

TABLE2
PARAMETERS OF THE DIFFUSION MODEL

Para meter	m	a	b	λ	g
Value	29774	0.08	0.92	0.12	1.0
Para meter	p_1, p_2	q_{11}	q_{12}	q_{21}	q_{22}
Value	0.0001	0.13	0.5	0.27	0.32
Para meter	θ	x_1	x_2	y_1	y_2
Value	-0.005	1175	27271	328	1000

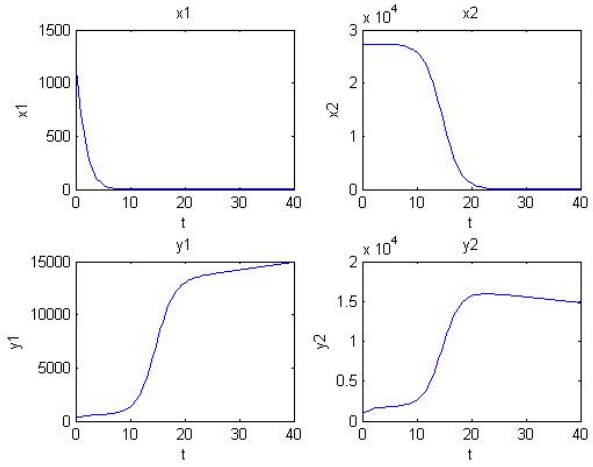

Figure.2. Variations of $x_1(t)$, $x_2(t)$, $y_1(t)$, and $y_2(t)$, respectively

As seen in Fig. 2, the value of $x_1(t)$ and $x_2(t)$ is large at the beginning, and its changing rate is less than 0. In contrast, the value of $y_1(t)$ and $y_2(t)$ is small at the beginning, and increases at each interval. As to the $y_1(t)$, at the beginning, its changing rate is greater than 0. However, the increment decreases with time, until it reaches its peak value, and thereafter its value decreases.

In contrast, $y_2(t)$ is small at the beginning, increases step by step, and then may decrease. There is a competitive relationship between $y_1(t)$ and $y_2(t)$. This status will be broken when an even more advanced, competitive mode appears. And this is consistent with the law of the advanced manufacturing mode diffusion. According to the analysis on the diffusion of $x_1(t)$, $x_2(t)$, $y_1(t)$, and $y_2(t)$, the conclusion is consistent with the conclusion drawn from the simplified linear matrix.

B. Influence of Government

It is necessary to analyze and discuss the influence of relevant parameters on the diffusion process. Matlab 7.1 was used to simulate the diffusion model. To study the influence of government on the competitive diffusion model, the values shown in Table 3 were applied, and the influence on the diffusion of $x_1(t)$, $x_2(t)$, $y_1(t)$, $y_2(t)$, and $y_3(t)$ was observed, as shown in Fig. 3.

TABLE3
DIFFERENT VALUES OF g.

Case	1	2
Value	1.0	1.5

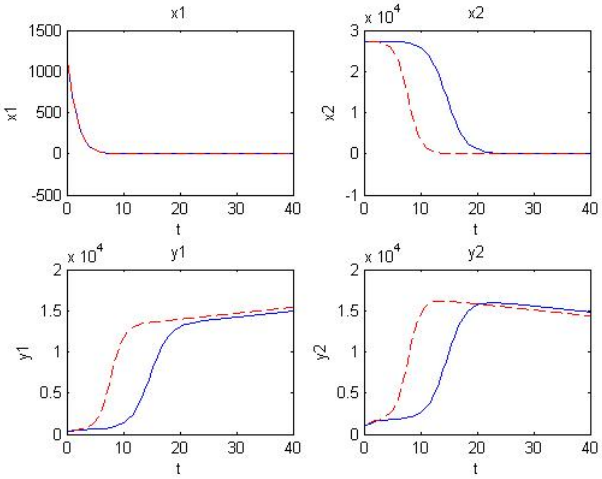

Figure. 3. Influence of g on diffusion

In Fig. 3, the solid lines represent case 1, and the dotted lines represent case 2. As g is increased, the diffusion of $x_1(t)$ is not influenced, whereas that of $x_2(t)$, $y_1(t)$, and $y_2(t)$ occurs sooner. The peak values of $y_1(t)$ and $y_2(t)$ also become larger, that is, the number of enterprises implementing modes A and B increases. In the same way, the influence of other parameters can be analyzed. The impact of government influence on the diffusion of the green manufacturing mode is obvious. Enterprises and governments can take different measures to influence the corresponding parameters, thus affecting the diffusion of the green manufacturing modes. For example, governments can promote the green manufacturing modes through advocacy, the establishment of demonstration enterprises, and the provision of preferential loans, as well as other measures, such as providing more capital, improving technology, setting up technology transfer and application guidance centers, and other policies to further accelerate the diffusion rate.

IV. PARAMETER IDENTIFICATION OF THE DIFFUSION MODEL

The parameters in the diffusion model in Section 3 include g, p, q, θ, a, b, and β, and as is known, parameters have great impact on diffusion process. Thus, it remains to identify g, p, q, and θ. To do this, a parameter identification method is proposed. It is an optimization problem, and an objective function chooses the square of the distance between y_{ij} and their real values is used to show the error in the estimated values. Meanwhile, the constraints of the diffusion model should be satisfied. This is a nonlinear optimization problem, and can be solved by connotative enumerative search methods, like genetic algorithms [13]. Thus, we combine the parameters of the competitive diffusion model with the data in Table 1 to form an optimization model. The specific method is as follows:

(1) Objective function: $\min \sum_{i=1}^{6}\sum_{j=1}^{3}(y_{ij}-y_{ij}^{*})^2$

Where, y_{ij} is the estimated number of enterprises implementing the j th manufacturing mode in the i th year and y_{ij}^{*} is the actual number of enterprises implementing the j th manufacturing mode in the i th year.

(2) Constraints:

$$\frac{dx_{i1}}{di}=-\lambda x_{i1}-(p_1+q_{11}\frac{am-x_{i1}}{am})x_{i1}-(p_2+q_{12}\frac{am-x_{i1}}{am})x_{i1}$$

$$\frac{dx_{i2}}{di}=\lambda x_{i1}-(p_1+gq_{21}\frac{bm-x_{i1}}{bm})x_{i2}-(p_2+gq_{22}\frac{bm-x_{i2}}{bm})x_{i2}$$

$$\frac{dy_{i1}}{di}=(p_1+q_{11}\frac{am-x_{i1}}{am})x_{i1}+(p_1+gq_{21}\frac{bm-x_{i2}}{bm})x_{i2}-\theta y_{i1}$$

$$\frac{dy_{i2}}{di}=(p_2+q_{12}\frac{am-x_{i1}}{am})x_{i1}+(p_2+gq_{22}\frac{bm-x_{i2}}{bm})x_{i2}+\theta y_{i1}$$

$$y_{i2}=m-x_{i1}-x_{i2}-y_{i1}$$

$$1\le g\le 1.01,$$

$$0.2\le q_{11},q_{12},q_{21},q_{22}\le 0.7$$

$$0.0001\le p_1,p_2\le 0.01$$

$$-0.1\le\theta\le 0.1$$

where, x_{i1} is the number of enterprises that have the ability but are not implementing the green manufacturing mode in the i th year, x_{i2} is the number of enterprises that do not have the capability to implement the advanced manufacturing mode in the i th year, y_{i1} is the number of enterprises implementing the green manufacturing mode, y_{i2} is the number of enterprises implementing the second advanced manufacturing mode. The initial values of $x_{i1}, x_{i2}, y_{i1}, y_{i2}$ are 1175, 27271, 328, 1000, respectively.

(3)According to the above objective function and constraints, a genetic algorithm is utilized to obtain the optimal parameter values of g, p, q, and θ using Matlab 7.1. The values obtained are shown in Table 4. Based on the data in Table 4, the number of enterprises implementing the two modes can be estimated, as shown in Table 5.

TABLE 4
OPTIMAL PARAMETER VALUES

Parameter	m	a	b	λ	g
Value	29774	0.08	0.92	0.12	1.0
Parameter	p_1	p_2	q_{11}	q_{12}	q_{21}
Value	0.0003	0.0013	0.309	0.6981	0.3356
Parameter	q_{22}	θ	x_1	x_2	y_1
Value	0.3147	0.0162	1175	27271	328

TABLE 5
ESTIMATED AND ACTUAL NUMBERS OF ENTERPRISES

Time Mode	2005	2006	2007	2008	2009	2010
A(real)	328	335	704	1180	1340	1742
Estimated	328	545	720	913	1222	1770
Error	0%	62.69%	2.27%	22.6%	8.81%	1.61%
B(real)	1000	1238	1771	2139	2405	2617
Estimated	1000	1443	1746	1991	2312	2842
Error	0%	16.56%	1.41%	6.92%	3.87%	8.60%

Table 5 shows the results of using the diffusion model to estimate the number of enterprises implementing each advanced manufacturing mode. There is some error between the estimated and real values, but this is controlled below 15% in average, which is feasible in practice.

V. CONCLUSIONS

The development of the green manufacturing modes and technologies provides a powerful consistent way for enterprises. In order to make rational decisions, enterprises must not only understand the philosophies and technologies of the green manufacturing mode, but also know the diffusion rules.

In this paper, we established the competition diffusion model of the green manufacturing mode analyzed the model and proposed a parameter identification method to obtain a more reasonable diffusion model. The model provided an explanation of the green manufacturing mode diffusion, thus and predicted its future application more accurately. Governments can develop appropriate policies to influence the relevant model parameters, thereby influencing the diffusion of advanced manufacturing modes.

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