Factor Analysis of the Advanced Manufacturing Mode Diffusion Based on System Dynamics

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***Abstract*—In order to reveal the factor impact on the advanced manufacturing mode diffusion, the influence of various factors in the diffusion process is studied from the perspective of system dynamics. To this end, firstly, factors in the advanced manufacturing mode diffusion are identified, which include both macro and micro factors from the perspective of whole industry and single enterprise respectively. Secondly, based on the factor analysis and system dynamics, both a macro and a micro system dynamic model of the advanced manufacturing mode diffusion are established. Then, the models are simulated by Vensim, and different parameter settings of the models are discussed. And then, the sensitivity analysis of factors is conducted. Finally, based on the results of system dynamics analysis, conclusions about the impact of these factors on the advanced manufacturing mode diffusion are drawn, which not only verifies the proposed models, but provides foundation for understanding the diffusion mechanism of the advanced manufacturing mode.**

***Index Terms*—Factor analysis, Advanced manufacturing mode diffusion, System dynamics, Sensitivity analysis**

I. Introduction

Advanced manufacturing mode plays an important role in not only the improvement of enterprise competitive ability, but also the promotion of manufacturing industries and economic development. So far, the implementation of the advanced manufacturing mode becomes the key problem for the development of manufacturing industries in the long run. Therefore, it's vital to understand the rules of the advanced manufacturing mode implementation process, and provide decision making foundation for enterprises and governments.

The implementation of advanced manufacturing systems involves the acceptance, adaptation, and application (collectively, the diffusion process) of advanced manufacturing modes. Researches on the advanced manufacturing mode have focused on the following aspects. (1) The concept, classification and characteristics of the advanced manufacturing mode; (2) The specific technologies of advanced manufacturing modes; (3) Applications of the advanced manufacturing mode. In terms of (1), reference [1] defined the advanced manufacturing mode from three aspects and levels, which are manufacturing philosophy, manufacturing system methods and specific technologies and methods. In terms of (2), reference [2] analyzed the characteristics and content of the computer aided design (CAD) technology. In terms of (3), reference [3] discussed the application of computer integrated manufacturing technologies in high-speed-wire plant of Tangshan Iron and Steel Corporation. Thus far, most research on the diffusion of advanced manufacturing modes is qualitative studies. For example, reference [4] studied the advanced manufacturing mode implementation in Huawei Technologies Ltd., whose aim was to build an advanced manufacturing mode for the global value network path. Though there are many references about the diffusion of innovation and product [5-6], there has been little reference to quantitative studies on the practical diffusion of advanced manufacturing modes. Reference [7] first studied the diffusion of CIMS, but gave only a simple diffusion model in which competition between manufacturing modes was not considered. Though the model discussed the government influence, it ignored the influence of many different factors in the diffusion process such as enterprise ability etc. Therefore, it is necessary to consider the different factors in the diffusion of various advanced manufacturing modes to further clarify the diffusion rules.

With the application of the computer science and the control theory into the social, economic and so on, the System dynamics has become a research tool for complex dynamic systems. There are many references to factor analysis in various fields by system dynamics. For example, reference [8] defined the analyzing framework of the industrial cluster effect, and analyzed the influence of each factors in the cluster. Reference [9] tested the sensitivity of system dynamics model on the college's developing strategy. Reference [10] established the model of private vehicles' consumption and analyzed the sensitivity of the vehicle's amount on urban railway system. These researches provide foundation for the factor analysis of the advanced manufacturing mode diffusion.

The diffusion of the advanced manufacturing mode is a long term systematic engineering which consists of a variety of factors. Considering the characteristics of the advanced manufacturing mode, as well as factors in the advanced manufacturing mode diffusion, this paper proposed both a macro model and a micro system dynamic

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model of the advanced manufacturing mode diffusion, and discussed the factor influence through dynamic models.

II. DIFFUSION FACTORS OF THE ADVANCED MANUFACTURING MODE

As a combination of philosophy, technologies and management, the diffusion of the advanced manufacturing mode has its specific diffusion characteristics besides products and technology diffusion. To establish the system dynamic model, the factors need to be identified clearly.

A. Factors from the Macro Perspective

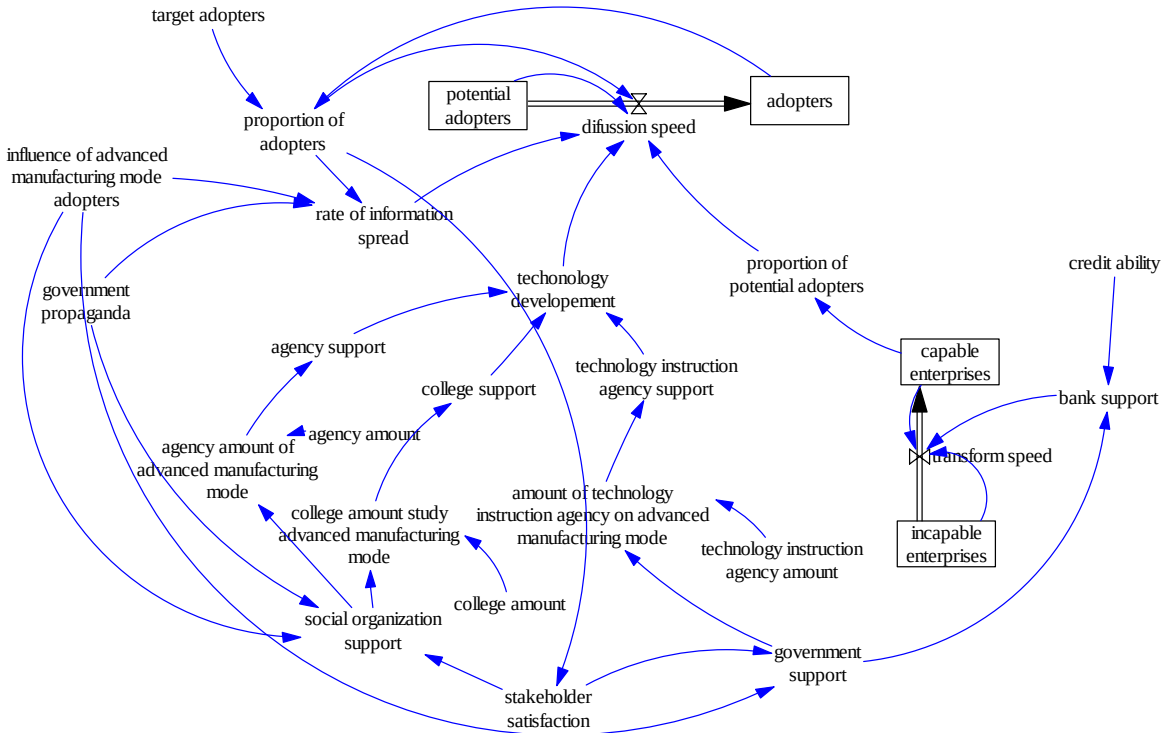

Figure.1 Macro system dynamics model of the advanced manufacturing diffusion

Factors from the macro perspective are factors which have an effect on the whole manufacturing industry. These factors include the influence of advanced manufacturing mode adopters, government propaganda, agency amount, college amount, technology instruction agency amount, and credit ability. Adopter influence refers to the demonstration of enterprises with the advanced manufacturing mode to other enterprises, and government propaganda stands for the influence of government propaganda to the advanced manufacturing mode diffusion. The amount of agency, colleges and technology instruction agency has impact on the technology development and application of the advanced manufacturing mode. Credit ability means the bank's intention to provide capital to enterprises for advanced manufacturing mode adoption.

B. Factors from the Micro Perspective

Factors from the micro perspective are factors which have impacts on the single enterprise. The factors are as follows: consumer requirement, pressure from competitors, implementation risk of the advanced manufacturing mode, superiority of the advanced manufacturing mode, match degree between enterprise culture and the mode, government tax revenue support, credit ability, financial status, human resource, enterprise scale, organization structure. These factors can be divided into two kinds: one is factors which influence the desire of the advanced manufacturing mode adoption, and include consumer requirement, pressure from competitors, implementation risk of the advanced manufacturing mode, superiority of the advanced manufacturing mode, match degree between enterprise culture and the mode. Meanwhile government tax revenue support, credit ability, financial status, human resource, enterprise scale, organization structure have impact on the cooperation's ability to implement the advanced manufacturing mode.

From the above analysis on factors of the advanced manufacturing mode diffusion, system dynamic models from macro and micro perspective can be established as follows.

III. MACRO DYNAMIC MODEL OF THE DIFFUSION

A. Hypothesis

H1 The advanced manufacturing mode is more competitive than the traditional manufacturing mode, which is more than the profit ability of enterprises. With the implementation of the advanced manufacturing mode, stakeholders' satisfaction is improved, which may lead to their desire to support the advanced manufacturing mode diffusion.

H2 The total number of target enterprises is fixed.

H3 The interactive effect of different factors is excluded from the model.

According to above hypothesis, the macro system dynamics model of the green manufacturing diffusion is shown in Fig.1.

B. Parameter Setting

In order to utilize system dynamic model to analyze the factors, the factors are measured in the following ways.

(1)The number of the target enterprises z is 20000, and the number of the current adopter y is 1000 at the beginning. x_1 is the initial number of enterprises without ability to adopt the advanced manufacturing mode and x_1 = 18500. x_2 is the initial number of enterprises with ability to adopt the advanced manufacturing mode.

(2) Adopter influence a_1 is 0.2, government propaganda a_2 is 0.1, and credit ability a_3 is 0.15. These parameters can be calculated by Eq. (1).

$$a_1 = \frac{r_1 - r_2}{r_1} \quad a_2 = \frac{g_1}{g_2} \quad a_3 = \frac{q_1 - q_2}{q_1} \qquad (1)$$

Where, r_1, r_2 represents the adopter's average profit from assets and the non-adopter's profit from assets respectively. g_1, g_2 represents the number of government public document about the advanced manufacturing mode and total public document about the industries respectively. q_1, q_2 represent the credit quota for the advanced manufacturing mode adopters and common enterprises *respectively.*

（3）Agency amount b_1, college amount b_2, technology instruction agency amount b_3 are set as 1000.

C. Factor Analysis on Macro Model

Sensitivity analysis is utilized to analyze factors in macro model. Change one factor every time by the same rate while keep others unchanged. Then the curve of adopter's amount can be obtained to show the effect of different factors on the diffusion process.

Definition 1: If parameter X is changed, and output is Y, sensitivity S can be defined by Eq. (2):

$$S(t) = \left| \frac{\frac{\Delta Y(t)}{Y(t)}}{\frac{\Delta X(t)}{X(t)}} \right| \qquad (2)$$

First, keep the other parameters unchanged and increase the adopter influence, government propaganda, agency amount, college amount, technology instruction agency amount, credit ability to 1.1 times of their initial value respectively. Then keep other parameters unchanged and decrease the adopter influence, government propaganda, agency amount, college amount, technology instruction agency amount, credit ability to 0.9 times of their initial value respectively. And the results are shown in Fig.2, Fig.3, Fig.4 and Fig.5. From the figures, it can be inferred that the sensitivity of adopter amount to other parameters is rational and can be used for factors analysis.

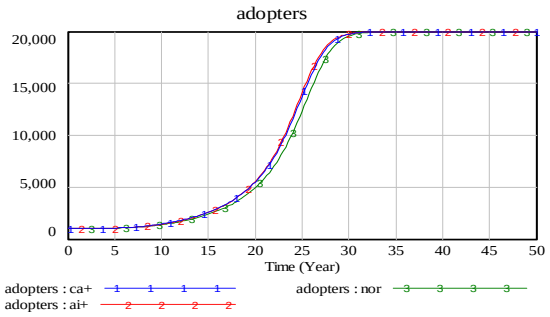

Figure.2 Change of adopter amount with variables 0.1+

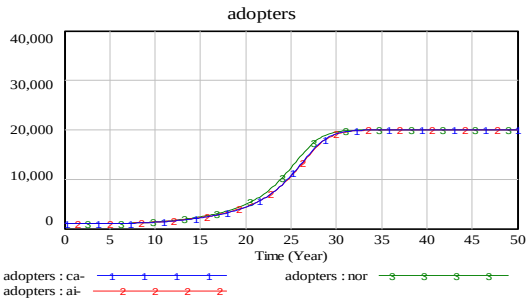

Figure.3 Change of adopter amount with variables 0.1-

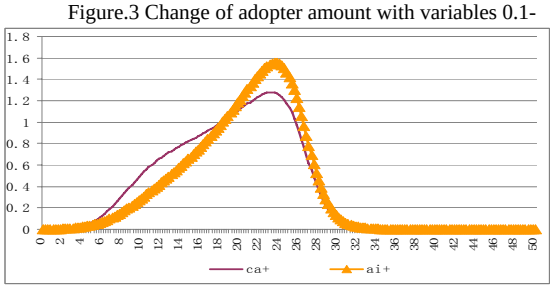

Figure.4 Sensitivity of adopter with variables 0.1+

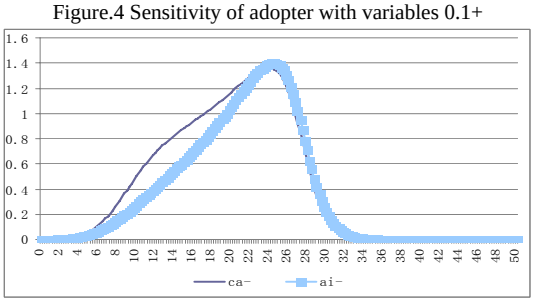

Figure.5 Sensitivity of adopter with variables 0.1-

Fig.2 and fig.3 describes the adopter amount changing curve when credit ability (labeled as *ca*) and adopter influence (labeled as *ai*) increase and decrease 10 percents respectively. From the figure, it can be concluded that the change of both parameters have effects on the diffusion speed of the advanced manufacturing mode. The peak value of sensitivity on adopter influence is higher than that of credit ability, but the time of peak value reaches later. It means the adopter influence's impact on diffusion is bigger than that of the credit ability, but it has delayed effect. In the same way, impact of other macro factors can be obtained as shown in Table.1, and ranked from high to low as follows: adopter influence, credit ability,

government propaganda, technology instruction agency amount, college amount, agency amount.

TABLE 1
SENSITTVITY ANALYSIS OF FACTORS

Factor	Factor change	Time(year)	Sensitivity
a_1	10%	23	1.539
	-10%	23	1.341
a_2	10%	23	0.745
	-10%	23	0.704
a_3	10%	23	1.278
	-10%	23	1.348
b_1	10%	23	0.273
	-10%	23	0.279
b_2	10%	23	0.336
	-10%	23	0.335
b_3	10%	23	0.692
	-10%	23	0.676

IV. MICRO DYNAMIC MODEL OF THE DIFFUSION

A. Hypothesis

H1 With the increase of match degree between the specific enterprise and the advanced manufacturing mode, the satisfaction level of the enterprises' stakeholders also improves.

H2 The diffusion process of the advanced manufacturing mode in a certain enterprise is a learning process. It is influenced by two kinds of factors. One is the enterprise's desire to adopt the mode, and the other is the enterprise's ability to adopt it. They interact and influence the match degree between the enterprise and the advanced manufacturing mode.

According to above hypothesis, the micro system dynamics model of the green manufacturing diffusion is shown in Fig.6.

B. PARAMETER SETTING

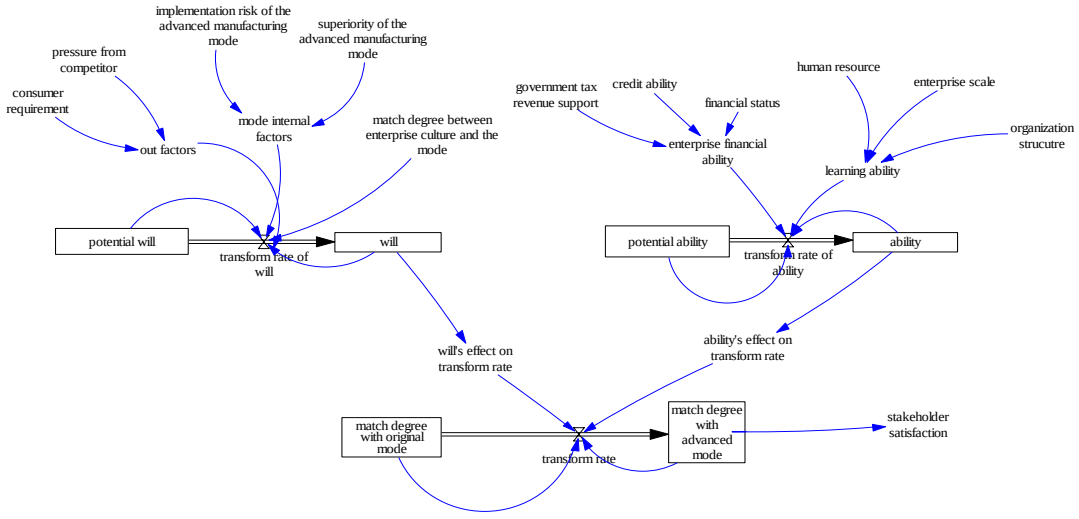

Figure.6 Micro system dynamics model of the advanced manufacturing diffusion

The factors are measured by the following variables:

(1)The enterprise's potential desire to implement the advanced manufacturing mode m, enterprise's potential ability to implement the advanced manufacturing mode n, and the match degree between the enterprise and its original manufacturing mode l are all set as 1. The initial values of enterprise's desire to implement the advanced manufacturing mode m_1, enterprise's ability to implement the advanced manufacturing mode n_1 and the match degree between enterprise and the advanced manufacturing mode l_1 are all 0. The range of variables is from 0 to 1.

(2)The value of consumer requirement c_1 is 0.2, pressure from competitors c_2 is 0.3, implementation risk of the advanced manufacturing mode c_3 is 0.25, superiority of the advanced manufacturing mode c_4 is 0.35, and match degree between enterprise culture and the mode c_5 is 0.2. They can be calculated by Eq. (3).

$$c_1 = \frac{p_1 - p_2}{p_1} \quad c_2 = \frac{c_{21}}{c_{22}} \quad c_3 = \frac{v_1 - v_2}{v_1} \quad c_4 = \frac{v_3 - v_4}{v_3}$$
$$c_5 = \frac{c_{51}c_{54} + c_{52}c_{53}}{2c_{52}c_{54}} \qquad (3)$$

Where, p_1, p_2 represent the consumer satisfaction of the enterprise implementing the advanced manufacturing mode and the average level in its industry respectively. c_{21}, c_{22} represent the number of competitors with the advanced manufacturing mode and the number of its total competitors respectively. v_1 represents the average cost for adopting the advanced manufacturing mode, v_2 represents the average cost of adopting the common manufacturing mode, v_3 represents the average profit for implementing the advanced manufacturing mode, v_4

represents the average profit for implementing common manufacturing mode. c_{51} represents the number of clauses about innovation, c_{52} represents the total number of enterprise's clauses. c_{53} is the amount of benefit for innovation, and c_{54} is the amount of enterprise's total benefit.

(3) The value of government tax revenue support d_1 is 0.3, credit ability d_2 is 0.35, financial status d_3 is 0.3, human resource d_4 is 0.25, enterprise scale d_5 is 0.4, organization structure d_6 is 0.1. They can be calculated by Eq. (4).

$$d_1 = \frac{t_1 - t_2}{t_1} \qquad d_2 = \frac{e_1 - e_2}{e_1} \qquad d_3 = \frac{e_3 - e_4}{e_3}$$

$$d_4 = \frac{s_1 - s_2}{s_1} \quad d_5 = \frac{v_5 - v_6}{v_5} \quad d_6 = \frac{h_1 - h_2}{h_1} \qquad (4)$$

t_1, t_2 represent the government tax revenue support for enterprises with the advanced manufacturing mode and common enterprises respectively. e_1 is the preferential credit of enterprises with the advanced manufacturing mode and e_2 is the credit amount of enterprises with the common manufacturing mode. e_3 is the average debt level of enterprises with the advanced manufacturing mode, e_4 is average debt level of enterprises with common manufacturing mode. s_1, s_2 are the number of senior staffs in the enterprise and that of the average level respectively. v_5, v_6 are the asset of the enterprise and that of the average level respectively. h_1, h_2 represent the administrative levels of the industry average level and that of the enterprise respectively.

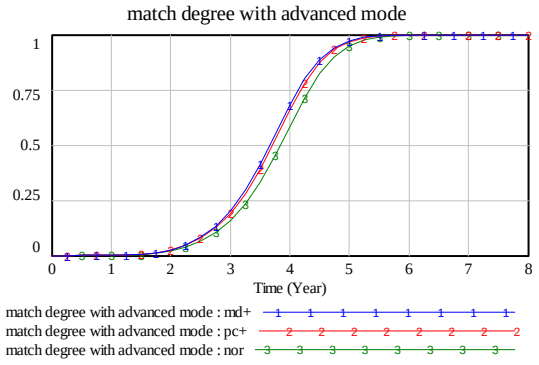

Figure.7 Change of match degree with variables 0.1+

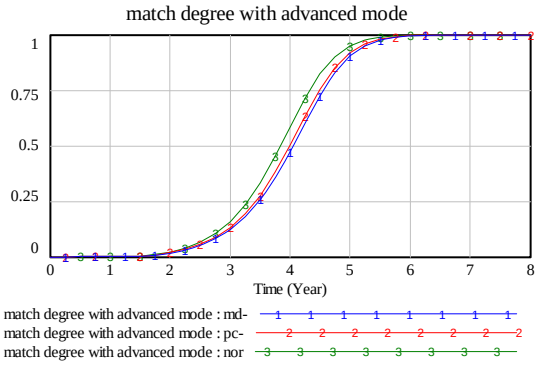

Figure.8 Change of match degree level with variables 0.1-

C. Factor Analysis on Micro Model

Similar to factor analysis on macro model, first, keep the other parameters unchanged and increase the consumer requirement, pressure from competitors, implementation risk of the advanced manufacturing mode, superiority of the advanced manufacturing mode, match degree between enterprise culture and the mode, government tax revenue support, credit ability, financial status, human resource, enterprise scale, organization structure to 1.1 times of their initial value respectively. Then keep the other parameters unchanged and decrease the consumer requirement, pressure from competitors, implementation risk of the advanced manufacturing mode, superiority of the advanced manufacturing mode, match degree between enterprise culture and the mode, government tax revenue support, credit ability, financial status, human resource, enterprise scale to 0.9 times of their initial value respectively. And the result is shown in Fig.7, Fig.8, Fig.9, and Fig.10. From the figures, it can be inferred that the sensitivity of adopter amount to other parameters is rational and can be used for factor analysis.

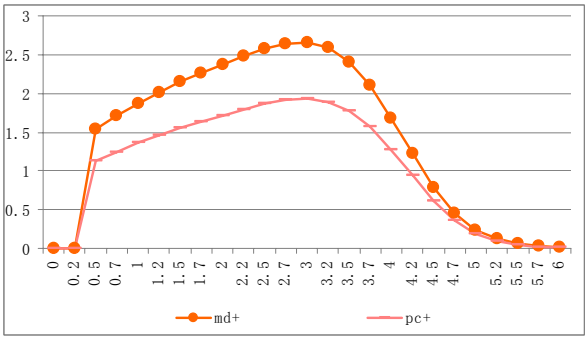

Figure.9 Sensitivity of match degree with variables 0.1+

Fig.7 and Fig.8 describes the match degree of the advanced manufacturing mode changing with match degree between enterprise culture and the mode (labeled as *md)* and pressure from competitors (labeled as *pc*) increase and decrease 10 percents respectively. From the figure, it can be concluded that the change of both parameters have effects on the diffusion speed of the advanced manufacturing mode. The peak value of sensitivity on match degree between enterprise culture and the mode is higher than that of pressure from competitors, and its peak comes earlier. It means the impact of *md* on diffusion is bigger than that of *pc*, and it has earlier effect. In the same way, impact of other micro factors can be obtained as shown in Table.2, and ranked from high to low

as follows: match degree between enterprise culture, pressure from competitors, superiority of the advanced manufacturing mode, implementation risk of the advanced manufacturing mode, consumer requirement, enterprise scale, financial status, credit ability, human resource, government tax revenue support, and organization structure.

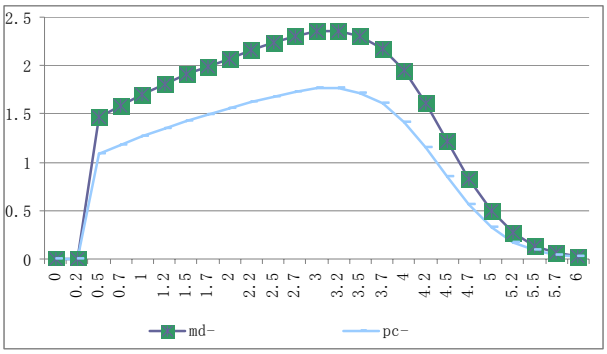

Figure.10 Sensitivity of match degree with advanced manufacturing mode with variables 0.1-

TABLE 2
SENSITTVITY ANALYSIS OF INFLUENCING FACTORS

Factor	Factor change	Ttime(year)	Sensitivity
c_1	10%	3	0.676
	−10%	3	0. 654
c_2	10%	3	1.933
	-10%	3	1.765
c_3	10%	3	0.828
	-10%	3	0.796
c_4	10%	3	1.774
	-10%	3	1.631
c_5	10%	3	2.661
	-10%	3	2.353
d_1	10%	3	0.093
	-10%	3	0.100
d_2	10%	3	0.183
	-10%	3	0.211
d_3	10%	3	0.201
	-10%	3	0.234
d_4	10%	3	0.163
	-10%	3	0.184
d_5	10%	3	0.251
	-10%	3	0.306
d_6	10%	3	0.058
	-10%	3	0.061

V. COMPREHENSIVE ANALYSIS ON FACTORS IN THE DIFFUSION

A. Analysis on Different Types of Factors

Factors which have impact on the diffusion of the advanced manufacturing mode are as follows: adopter influence, government propaganda, agency amount, college amount, technology instruction agency amount, credit ability, consumer requirement, pressure from competitors, implementation risk of the advanced manufacturing mode, superiority of the advanced manufacturing mode, match degree between enterprise culture and the mode, government tax revenue support, credit ability, financial status, human resource, enterprise scale, organization structure. According to the system dynamics analysis in the macro and micro model, it can be concluded that the impact of factors influencing the enterprise's implementation desire is bigger than that of factors influencing the ability in the diffusion of the advanced manufacturing mode. This is consistent with the practical status of the advanced manufacturing mode's diffusion. This phenomenon owes to the fact that the selection, implementation and promotion of the advanced manufacturing mode are a long-term systematic project. The long-run characteristics and the complexity led it impossible for enterprises implement the advanced manufacturing model for short-term benefits. In the long run, it is necessary to strengthen the enterprise awareness of the importance of implementing the advanced manufacturing mode, and the factors (which influencing the enterprises' desire) play important roles in this process. In the contrast, the impact of technological factors become weaker as the advanced manufacturing mode becomes more and more mature.

B. Comprehensive Analysis of the Macro and Micro Factors

Factors in the diffusion of the advanced manufacturing mode are analyzed from both the macro and micro perspective by system dynamics. And the two models are connected by the concept of stakeholder satisfaction. Macro dynamic model focused on the implementation of the advanced manufacturing mode in the whole industry, while micro model is about factors influencing a single enterprise's adoption of the advanced manufacturing mode. The mechanism of the advanced manufacturing mode diffusion is: single enterprise's adoption of the advanced manufacturing mode is the basis of mode diffusion in the industry. By the implementation of the advanced manufacturing mode, stakeholder satisfaction of enterprises is improving, and as a result, stakeholder satisfaction of the industry increases, which also led to greater desire to implement the advanced manufacturing mode in industries. Then the bench marking effects stem from the adoption of the advanced manufacturing mode, which also inspire single enterprise's potential willing to adopt. Therefore, there are inherent relationships between macro model and micro model, and they accord with the rules in the advanced manufacturing mode diffusion.

VI. CONCLUSIONS

The diffusion of the advanced manufacturing mode is a systematic and long-term process, and there are various factors influencing the diffusion. This paper analyzes the factors impact on the diffusion of the advanced manufacturing mode by system dynamics. Both a macro dynamic model and a micro dynamic model of the advanced manufacturing mode diffusion are established, and the models are simulated by Vensim. Then, impacts of different factors are analyzed based on dynamic models,

and corresponding conclusions are drawn. This will be helpful for enterprises and government to make decisions on key factors when implementing the advanced manufacturing mode. And enterprises can adjust the model to their own needs and find out the key factors to speed up the implementation of the advanced manufacturing mode so as to enhance their competitive ability.

ACKNOWLEDGEMENT

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