Modeling and Analysis on PID Feedback Control of Advanced manufacturing Mode Competition Diffusion

Haiwang Cao1,*, Chaogai Xue2, Wujun Cao2, Mengchu Zhou3

1. Department of Electronic and Communication Engineering, Zhengzhou Institute of Aeronautical Industry Management, Zhengzhou, China
2. School of Management Engineering, Zhengzhou University, Zhengzhou, Henan, China
3. Department of Electrical and Computer Engineering, New Jersey Institute of Technology, Newark, New Jersey, United States

Abstract: To control the advanced manufacturing mode diffusion and obtain the desired diffusion effect, this paper firstly studies the modeling and analysis of advanced-manufacturing-mode competition diffusion (ACD) by PID feedback control method. First, the influencing factors of ACD process and its external intervention are analyzed and practical strategies and their corresponding control units are discussed. Combining with external intervention, the basic thinking and strategies of controller design are given. Then, as to the referred input, PID feedback controllers are designed, and PID feedback control model of ACD are built. And then, the properties of control model are analyzed, and qualitative results are given. Finally, the application of the proposed model is simulated by Matlab 7.1 in a case study of practical advanced manufacturing modes diffusion. The results are consistent with the qualitative analysis, thereby verifying the correctness of the proposed model. This work discloses external intervention rules in ACD, designs the PID feedback controller, decreases the blindness of pole assignment control method, and realizes the control on ACD to desired diffusion effect both in theory and in practical strategies. It also provides theoretical basis, control methods and intervention strategies for enterprises’ decision making and government regulation.

Keywords: feedback control; external intervention; control strategies; parameter identification; advanced manufacturing mode competition diffusion

1. Introduction

To various targeted markets and enhance their core competitiveness, it has become an ongoing trend for enterprises to implement advanced manufacturing modes, such as re-manufacturing/green manufacturing, Just In Time (JIT), network manufacturing, supply chain management, computer integrated manufacturing system, and total quality management (TQM), etc.. However, the implementation effect of advanced manufacturing mode is far from being satisfactory [1-2]. Therefore, many countries promote various policies to develop manufacturing industries, e.g. industry 4.0 in Germany, and energy & manufacturing competitiveness partnership in U.S. From references and field investigation, external intervention is recognized as an effective way to promote manufacturing modes. External intervention and ACD constitute a close loop system, and external intervention is the control exerted on ACD. It has been modeled and analyzed that external intervention does have the influence on the diffusion process in theory [3]. However, how to control the ACD process, and how to realize the effect of external intervention in practice? For the better application of external intervention in mode diffusion in actual industrial situations, this paper deals with what ways can be used to achieve the desired diffusion effect of ACD and what control strategies can be taken in external intervention.

In our view, the implementation of advanced manufacturing modes involves the acceptance, adaptation, and application of standardized concept, philosophy, structure and advanced manufacturing methods collectively [4-5]. Our first idea about ACD came from product diffusion [6] and innovation diffusion [7], which have been important branches of spread theory since the proposal of Bass model. Different from products, advanced manufacturing modes represent novel recognition, concepts, and methods used in manufacturing industries, which may vary with different manufacturing philosophies. Their implementation is the innovation diffusion of concepts, philosophies and manufacturing practice, and certainly brings about the development of new techniques, management, as well as new products. Therefore, the work [5,8] proposed mode diffusion and studied ACD to master rules in the implementation of advanced modes. Then, to model external intervention, we proposed an external intervention model based on the novel thought that ACD and external intervention constitute a closed-loop feedback control system. However, how to realize external intervention effect and what control strategies to be taken are also important in practical external intervention. Based on the modeling, analysis and on ACD and its external intervention, we lever-age feedback controller design methods to better solve the problem: how to control and obtain the desired diffusion effect of ACD through external intervention. To this end, this work designs and analyses the controller of ACD so as to provide scientific evidence and practical control strategies for enterprises and government to make better decisions.

2. Literature review

2.1 Advanced manufacturing mode diffusion

Considerable effort on advanced manufacturing modes [9] has been conducted, but the limited work regarding to advanced manufacturing mode diffusion have been briefed:

1) Diffusion mechanism of manufacturing modes. They are mainly quantitative studies about diffusion paths, ways and mechanisms in different ACD. For example, Xu [4] discusses how to promote the implementation of green manufacturing from three aspects (market incentives, government and enterprise behavior).

2) Diffusion models of manufacturing modes. From a diffusion perspective, the internal promotion and application rules of advanced modes can be studied by establishing dynamic models. They can be divided into two categories: the macro level (aggregate level) based on overall statistical behavior of potential adopters, and the micro level (individual level) based on the adoption decision of potential adopters. For example, the diffusion behavior of computer integrated manufacturing (CIM) philosophy is studied by Xue [5]. And a competition diffusion model of multiple-advanced manu-facturing modes in a cluster environment is proposed [8], considering enterprise capacity, mode competition and external influence.

3) Problems related to advanced manufacturing mode diffusion. This mainly focused on some specific problems in application fields, such as multi-stages, influencing factors and optimization in mode diffusion. For example, Xue and Zhou [3] study the effectiveness optimization of external intervention in multi-ACD based on pole assignment and control parameters.

4) Empirical studies on advanced manufacturing mode diffusion. For example, through a field investigation, Li [10] studies the dynamic evolution path of an advanced manufacturing mode in a company, and proposed some countermeasures and suggestions for mode development.
The above research provides a theoretical basis for the implementation of advanced manufacturing modes and promotes their in-depth application. However, how to further apply advanced modes by external intervention and what practical intervention strategies can be taken to promote the diffusion process, have not yet been studied.

2.2 External intervention in advanced manufacturing mode diffusion

External intervention refers to the external factors or strategies to change the external environment, enterprise capacity or technological factors so as to promote the implementation of advanced modes. External intervention may be governments, financial institutions, scientific research institutes and industrial associations, and they have a combined effect on ACD. The present studies on external intervention mainly include the following issues:

1) Intervention mechanisms. Intervention mechanisms refer to constellation of entities and activities that are organized such that they regularly bring about external or internal intervention in mode diffusion. These studies [11,12] include different perspectives in different fields. For example, Hu [11] studies intervention mechanism of achievement transformation in government-funded scientific and technological projects.

2) Intervention models [13,14]. These studies include different methods and models of government policies and interventions, and they can be divided into qualitative and quantitative methods. For example, Shi and Xie [13] analyze the non-equilibrium degree of a real estate market and government intervention timing based on a non-equilibrium model and short-side rules.

3) Intervention strategies. They are mainly related to detail applying polices in different industries. For example, Fu et al. [15] studied government strategies in industrial technology innovation.

4) Empirical intervention studies in different fields. For example, Chang et al. [16] study the promotion policies of manufacturing automation in Taiwan.

However, current studies on external intervention are mainly qualitative studies in specific cases, and there is no reference on formal external intervention model of ACD. Our prior work firstly proposes an external intervention model in multi-ACD in theory and shows its importance. However, as the blindness of pole assignment method, the existing external intervention model in multi-ACD doesn’t show how to realize intervention effect. Therefore, it is meaningful to discuss how to realize external intervention effect and obtain practical intervention strategies.

2.3 Controller design and strategies

From the control perspective, ACD and its external environment constitute a feedback loop control system. Given the practical decision-making condition of external intervention, controller design methods in control theory can be utilized to achieve desired diffusion effect. If we can build relations between control methods and external intervention, controller design methods in control engineering can be re-ferred. At present, though there are few studies on external intervention in mode diffusion based on quantitative control methods, studies about control methods in other fields can be briefed as following aspects:

1) Control models in different fields. In different applications, different control models (such as PID control) are widely used. For example, Hriz and Zhou [17] model and control discrete even dynamic systems with Petri nets and other tools.

2) Different control methods and algorithms. They include various methods and algorithms in control theory, such as robust control, H∞ control, adaptive control, as well as methods and algorithms such as simulated annealing algorithm, genetic algorithm, evolution algorithm etc. For example, Alv [18] proposes an improved genetic algorithm to optimize a nonlinear PID control of hydraulic crane.

3) Application of control methods in different fields. For example, Hoffmann etc. [19] discuss precision flight control for a multi-vehicle quadrotor helicopter tested.

From the above, external intervention is the control on advanced manufacturing mode diffusion, but lack detailed control methods. As discussed in prior work [3], external intervention in multi-ACD is a kind of management control system and can be modeled as a feedback control system. To realize control effect, it is meaningful to utilize control methods to improve practicability of external intervention model once the relations between control units and external intervention strategies have been built, but there is no reference in this field.

3. External Intervention strategies and their corresponding control functions

Different intervention strategies may have different effect on ACD process. Some intervention strategies may have multiple effects on ACD. If we take intervention process as a kind of input-output model, the intervention strategies as input, and the effect of ACD process as output, then external intervention can be divided into some basic control functions (as shown in Figure 1. and they have fundamental influence on ACD. Generally, according to the intervention effect on diffusion process, the basic control functions of intervention strategies of ACD are as follows:

$$X(s) \rightarrow G(s) \rightarrow X_d(s)$$

Figure 1. Description of intervention relations.

1) Proportional relation

If the output and input of an intervention on ACD is proportional, then this relation is called proportional relation. As to the external intervention of ACD, this kind of control relation can have the effect of proportional increase.

2) Inertial relation

If the output and input of an intervention in ACD satisfy , then this relation is called inertia relation, where, T is the time constant, and K is the gain of inertia relation. When the input of an inertia relation is a unit step function, its output is non-periodical monotonic rise negative exponential curve, which accords with most practical intervention effect. As to the external intervention of ACD, this kind of control relation can have the effect of proportionality increase and delay.

3) Differential relation

If the output and input of an intervention on ACD satisfy , then this relation is called differential relation. When the input of a differential relation is a unit step function, its output is an impulse with infinite magnitude and zero duration. When the time constant of an inertia relation is very large, inertia relation can be taken as a differential relation. In general, a differential relation doesn’t exist alone, and it coexists with other relations.

4) Integral relation
If the output and input of an intervention on ACD satisfy , then this relation is called integral relation. When the input of an integral relation is a constant, its output is proportional to its time. As to the external intervention of ACD, this kind of control relation can have the proportional effect on time.

(5) Time-delay relation

If the output and input of an intervention on ACD are same except the delay time \( t \), i.e., the output is \( x(t-t) \), then this relation is called time-delay relation. As to the external intervention of ACD, this kind of control relation can have the delay effect on the number of enterprises implementing new modes.

Based on practical strategies and corresponding relations, we can discuss the controller design, build the control model of ACD, analyze its properties and apply its results into practical external intervention.

4. Control mechanism of ACD

4.1 Properties of ACD and its external intervention

ACD and its external intervention have following properties:

1. ACD is influenced by adopters, external environment and internal capacity of enterprises.
2. An advanced manufacturing mode may have its improved versions, even though they share a same philosophy.
3. The implementation of advanced manufacturing modes enables enterprises to gain competitive advantages.
4. External intervention strategies may have different effect on ACD, and they can be abstracted into different control relations.

4.2 Basic thinking of control model

As to the decision-making of ACD, decision-makers are more concern about the effect than control methods, i.e., they are more likely to set the objective of diffusion than to assign poles of a control model. Thus, it is more reasonable to have decision-makers set the objective of control (e.g. the diffusion effect of an advanced mode: 95% of total enterprises adopt the mode). Based on the diffusion effect set by decision-makers, the basic thinking of PID controller design is as follows: ACD and its external intervention constitute a feedback loop control system. External intervention model in ACD is a control on the diffusion. According to the decision-making objective, different controllers can be designed by control theory. Then the control model can be analyzed to obtain the desired properties, and combining with practical intervention strategies and control methods, reasonable intervention strategies can be made so as to obtain the desired effect of mode diffusion. The control system of ACD is shown in Figure 2.

From Figure 2, ACD is a plant, and external intervention is a control variable. Feedback controller can be designed based on ACD and external environment. The PID feedback control system model of ACD can be obtained.

4.3 Assumptions of ACD control model

Before studying the PID feedback control model of ACD, we make the following assumptions to simplify our discussion:

H1. Given the referred control objective of an advanced mode, PID feedback controller is designed to realize the desired diffusion effect.

H2. ACD and its PID feedback controller constitute a feedback loop control system.

H3. All enterprises can implement manufacturing modes with external intervention.

H4. In a given period, the diffusion of advanced modes is a mode competition diffusion process.

H5. All assumptions in ACD model [8] should be satisfied, such as constant constraint, enterprise’s willingness, and domination of one mode at a given time in an enterprise.

H1 states that the basic objective of controller design. H2 states the basic objective of feedback controller design. H3 state the role of external intervention in ACD. H4 state that control mode is based on ACD process. H5 states that the assumptions of ACD model must be satisfied.

Based on the above properties and assumptions, enterprises are divided into the following types:

1. \( x_1 \) enterprises that have already implemented a prototype mode.
2. \( x_2 \) enterprises that have already implemented the improved mode.
3. \( x_3 \) enterprises that would implement the advanced manufacturing mode, but are yet to do so.

According to assumption of ACD model, the number of these enterprises is finite, i.e., \( x_1 + x_2 + x_3 = m \), where \( m \) is the total number of enterprises.

5. Control system model of ACD

Based on the studies on ACD and external intervention, our PID feedback control model of ACD is built based on the following considerations:

1. According to the factor analysis and external intervention strategy analysis, the plant, variables, input, output and parameters are obtained. Based on reference [11], the state equation of ACD can be obtained.
2. Given the practical decision-making situation, the input of control system is the decision-making objective on a particular advanced mode \( x_{ref} \).
3. In virtue of signal follow property and considering its easy use, PID controller is utilized to design the feedback controller of ACD so as to reach its control objective.

5.1 State equation of ACD
According to control relations of external intervention and ACD model in reference [3,5,8], in a given period, all types of enterprises exist and their counts are \(x_1, x_2, \ldots, x_3\), which vary with time. The differential equation model of ACD is as follows:

\[
\begin{bmatrix}
\dot{x}_1 \\
\dot{x}_2
\end{bmatrix} =
\begin{bmatrix}
\frac{q_1 x_1 x_2}{m - \theta x_1 + k_1 u} \\
\frac{q_2 x_2 x_3}{m + \theta x_2 + k_2 u}
\end{bmatrix}
\]

\(Y = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}\)

(1)

where, \(x_3 = m - x_1 - x_2\). \(k_1\) and \(k_2\) are external intervention coefficient of the mode and its improved one. \(q_1\) and \(q_2\) are the inherent diffusion rate of \(x_1\) to \(x_3\), and \(\theta\) is the competition transferring coefficient from \(x_1\) to \(x_2\), which is decided by the competition advantage of each advanced manufacturing mode.

Model (1) is differential equation model of ACD, and it is the plant to be controlled. According to reference [3] and i.e., \(x_1 + x_2 + x_3 = m\), the differential equation can be approximately transferred as Model (2) by Lyapunov methods.

\[
\begin{bmatrix}
\dot{x}_1 \\
\dot{x}_2
\end{bmatrix} =
\begin{bmatrix}
\frac{q_1 x_1 x_2}{m} - \frac{q_1}{m} x_1 x_2 + \frac{(q_1 - \theta)}{m} x_1 \\
\frac{q_2 x_2 x_3}{m} - \frac{q_2}{m} x_1 x_2 + \frac{q_2}{m} x_2 + \theta x_2
\end{bmatrix} + \begin{bmatrix} k_1 \\ -k_2 \end{bmatrix} u
\]

(2)

As to model (2), to obtain the desired diffusion effect of a particular mode, i.e. the minimum difference between real number of adopter and the referred number, a PID feedback controller is designed as follows.

5.2 PID controller design of ACD

According to state equation of ACD, dynamic information in ACD is obtained. Then if the control signal is designed as the difference between real number and the referred number, the control on mode diffusion can be conducted. Generally, feedback is taken to design controllers. The feedback controller design is to determine a control law to make the system meet its performance requirement. When there is deviation between the real number and referred number, feedback controller will work, and compensate the disturbance of control parameters. The ACD feedback control relationship is shown in Figure 3.

![Diagram of ACD feedback control](image)

Figure. 3 Relationship between ACD and feedback control.

As shown in model (1) and considering the real external intervention, the diffusion of advanced modes is an affine nonlinear system, and it can be a linear model by approximate linear methods. Then optimal controller design methods can be used to obtain optimal parameters of feedback controller. And this feedback controller can be applied into the nonlinear system, and can realize the transform from the unstable initial state to stable state in a small range. In practice, the most popular control law is proportional, inertial, differential control, known as PID control. It can realize the signal tracking, and is easy to adopt. Therefore, we take PID controller to realize the track of ideal diffusion effect. It is composed of proportional unit, inertial unit and differential unit, and its input and output relation is:

\[
u(t) = K_p e(t) + K_i \int e(t) dt + K_d \frac{\text{d}e(t)}{\text{d}t}
\]

where, \(K_p\) is proportional coefficient, \(K_i\) is inertial coefficient, and \(K_d\) is differential coefficient.

To show the design of PID controller, \(x_2\) is taken as the controlled mode, and its ideal diffusion number is \(x_{ref}\). When PID controller is added into the ACD, its approximate linear model at stable point \((0, m)\) is as follows:

The most difficult part of PID controller design is determining \(K_p\), \(K_i\) and \(K_d\). Generally, there is no fixed method, and parameters vary with different systems. The parameters of PID controller of ACD also accord with rules of mode diffusion. Given the referred curve of mode diffusion, we take advantage of optimum PID controller design method based on constraints to design parameter \(K_p\), \(K_i\) and \(K_d\). The optimal model of PID controller design is shown as follows, in which the optimization objectives are total error, maximum error, and settling time to stable time.
Advanced modes can be adjusted, which also validates the meaning of external intervention in theory. Furthermore, with nonzero initial conditions in practice, when \( t \to +\infty \), \( x(t) \to 0 \), \( y(t) \to M \).

Feedback controller is designed to minimize the deviation between real mode diffusion and ideal mode diffusion. If it is controllable, then the feedback controller can be designed, and goto Step 2.

Step 3. Feedforward and PID feedback controller are linked as Fig. (3) and are applied in the control of ACD.

Step 2. According to parameter identification methods, the parameters of PID controller \( K_p, K_i, K_d \) can be obtained, and its PID controller parameter value is obtained. When the parameters of PID controller are obtained, the tracking on referred number of a particular mode in model (3) can be realized. This is meaningful for decision makers to intervene mode diffusion. With the PID feedback model, decision-makers only need to give the preferred objective of a particular mode, the proportional control, differential control, and inertial control strategies are added, then the optimal parameters. When the parameters of PID controller are obtained, the tracking on referred number of a particular mode in model (3) can be realized.

Theorem 1. Under zero input state (\( u=0 \)) and \( 0<q_1<q_2 \), \( P_1 (0, 0) \) is stable, \( P_2 (0, m) \) is stable, and \( P_3 \) is stable.

Theorem 2. With nonzero practical conditions, PID feedback control system of ACD is stable at \( P_2 (0, m) \).

Theorem 3. With nonzero practical conditions, System (3) can be controlled at its stable points, i.e., through external intervention, the implementation of advanced modes can be adjusted, which also validates the meaning of external intervention in theory.

Theorem 4. With nonzero practical conditions, PID feedback control system of ACD is also controllable at \( P_2 (0, m) \).

Theorem 5. With nonzero practical conditions, System (3) at \( P_2 (0, m) \) is observable.

### 5.3 PID feedback control model of ACD

As to ACD, the PID feedback control model can be obtained as follows:

Step 1. The controllability of approximate linear equation of ACD at equilibrium points is judged according to Lyapunov stability methods. If it is controllable, then the feedback controller can be designed, and goto Step 2.

Step 2. According to parameter identification methods, the parameters of PID controller \( K_p, K_i, K_d \) can be obtained, and its PID feedback controller is designed to minimize the deviation between real mode diffusion and ideal mode diffusion.

Step 3. Feedforward and PID feedback controller are linked as Fig. (3) and are applied in the control of ACD.

#### 6. Analysis on PID feedback control model

As to PID feedback controller model of ACD, its stability, controllability and observability are analyzed.

Theorem 1. Under zero input state (\( u=0 \)) and \( 0<q_1<q_2 \), \( P_1 (0, 0) \), \( P_2 (0, m) \), \( P_3 \) are three un-steady, steady and saddle equilibrium points of system (3) respectively. Furthermore, with nonzero initial conditions in practice, when \( t \to +\infty \), \( x(t) \to 0 \), \( y(t) \to M \).

Theorem 2. With nonzero practical conditions, PID feedback control system of ACD is stable at \( P_2 (0, m) \).

Theorem 2 shows the system consisted of PID feedback controller is stable, and it can be controlled to its desirable state.

Theorem 3. With and nonzero practical conditions, System (3) at \( P_2 (0, m) \) is controllable.

Theorem 3 shows that system (3) can be controlled at its stable points, i.e., through external intervention, the implementation of advanced modes can be adjusted, which also validates the meaning of external intervention in theory.

Theorem 4. With and nonzero practical conditions, PID feedback control system of ACD is also controllable at \( P_2 (0, m) \).

Theorem 4 shows if a referred state of advanced mode diffusion is given, the mode diffusion can be controlled around \( P_2 \) to its ideal amount.

Theorem 5. With nonzero practical conditions, System (3) at \( P_2 (0, m) \) is observable.
Theorem 5 shows the system is observable at its equilibrium state, i.e., when \( t=T \), the improved mode will monopolize the market. It also shows that it is possible to observe its state of ACD through controllers.

Theorem 6. With nonzero conditions, PID feedback control system of ACD is also observable at \( P_2(0, m) \). Theorem 6 shows external intervention in ACD can be observed. Theorem 3–6 shows the feasibility of PID feedback control model of ACD in theory.

7. Application and simulation

7.1 Relative parameters of the model

To apply the PID feedback control model of external intervention in ACD, parameters need to be obtained. Here, we take the implementation of computer integrated manufacturing as an example to show diffusion and external intervention effect. The related data of the mode is shown in Table 1.

Table 1 Number of enterprises

<table>
<thead>
<tr>
<th>Time</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>51</td>
<td>115</td>
<td>201</td>
<td>324</td>
<td>651</td>
<td>929</td>
</tr>
</tbody>
</table>

Some parameters of ACD can be obtained as follows:
(1) The time of origin of system (4) is set as 2005. From 2011 China Industrial Economy Statistical Yearbook [21], the number of enterprises implementing advanced manufacturing modes is obtained, i.e., \( m=236486 \).
(2) For quantitative results, other parameters of system (3) are obtained by the methods in [8] as shown in Table 2.

Table 2 Parameters of system

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>( M )</th>
<th>( x_1 )</th>
<th>( x_2 )</th>
<th>( q_1 )</th>
<th>( q_2 )</th>
<th>( \theta )</th>
<th>( k_1 )</th>
<th>( k_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>236486</td>
<td>51</td>
<td>5</td>
<td>0.15</td>
<td>0.35</td>
<td>0.04</td>
<td>0.01</td>
<td>0.05</td>
<td></td>
</tr>
</tbody>
</table>

According to the discussion on the ACD and its external intervention, the system is controllable and observable at \( P_2(0, m) \), then the PID feedback control model is discussed at point \( P_2(0, m) \).

7.2 Simulation and discussion

Matlab 7.11 is used to simulate the PID feedback control model of ACD. The referred advanced manufacturing mode is the improved one, and its ideal value is \( m \), i.e.:

\[
x_{t=30}^{\text{ref}} = \begin{cases} 
  m, & t \geq t^* \\
  0, & \text{otherwise}
\end{cases}
\]

Where, \( t^* \) is the intervention time. The diffusion with no intervention in the 30th, \( P_2(851, 156730) \) is taken as the intervention point, and ACD is simulated to show the external intervention effect. For clarification of these results, with \( t (t^*=30) \), the variations of \( x_1(t), x_2(t) \) and \( x_3(t) \) with no control are shown in Fig. (4). According to parameter identification method (model (4)), an improved self-adaptive genetic algorithm [20] is used to obtain the optimal value of \( K_p, K_i \) and \( K_d \). And the transfer function of PID controller is \( G(s) = \frac{70 + 249}{s + 12.44} \). For clarification of the results, with \( t \) as an independent variable, the variations of \( x_1 - x_3 \) with PID controller are also shown in Figure 4.

In Figure 4, solid lines represent mode diffusion without the controller, and dotted lines represent that with the PID controller. With the PID controller, the number of enterprises implementing prototype mode \( x_1 \) declines more sharply from the intervention point, and they transfer to the improved modes. The referred advanced manufacturing mode increases sharply to its ideal state with PID controller. The number of enterprises adopting improved version with the controller can be stable to the referred value given by decision maker, but the settling time to stable state decreases dramatically.

From the above analysis, we conclude: a) Active external intervention accelerates the implementation of advanced manufacturing modes. b) Through PID feedback controller ACD can be controlled to specific states. This conclusion is consistent with the practical role of external intervention in practice whose aim is to promote the implementation of particular advanced manufacturing mode to desired state and to reach the stable state with less settling time.

7.3 Control strategies
In practice, what external intervention strategies can be used to realize the control effect? Based on basic relations between control unit and real strategies, the following strategies can be adopted to obtain the intervention effect.

1) The proportional strategies such as setting typical demonstration enterprises, experimental application (e.g. funded by government) etc, have the effect to increase number of enterprises adopting new modes. The effect of proportional strategies should satisfy the optimal results of PID parameter Kp.

2) The integral strategies such as the intervention of financial services (preferential interest rate), change of market competition environment (e.g. industrial clusters) etc., have which have the effect to increase number of enterprises adopting new modes in a non-periodical monotonic rise negative exponential way. The effect of inertial strategies should satisfy the optimal results of PID parameter Ki.

3) The differential strategies such as different policies (concern on environment), change of market competition environment (e.g. industrial clusters) etc., have which have the effect to change settling time to stable state in ACD. The effect of differential strategies should satisfy the optimal results of PID parameter Kd.

8. Conclusions

In order to achieve the desired diffusion effect, government and enterprises need to understand the effect of external intervention on ACD, decrease the blindness of intervention method and what external intervention strategies should be taken.

In this paper, given the referred objective of decision makers, PID feedback control model of ACD is built and analyzed so as to obtain the desired intervention effect. Combined with corresponding relationships between control elements and practical strategies, external intervention strategies are discussed to realize the desired diffusion effect of ACD. The simulation on the model shows external intervention on the implementation of advanced manufacturing modes can be realized by PID feedback controller design.

This work is the first trial to answer the question: how to intervene into ACD and what control strategies can be taken to obtain desired diffusion effect both in theory and in practice. Through PID feedback controller design and the control strategies of ACD, it decreases the blindness of pole assignment and provides enterprises and government with effective external intervention ways to achieve the desired diffusion effect. Government can take advantage of conclusions to make better decisions concerning desired diffusion effect of particular modes, when to intervene, and what strategies can be taken to achieve desired intervention effect.

Conflict of interest

The author confirms that this article content has no con-flict of interest.

Acknowledgements

This research is supported by the National Natural Science Foundation of China under Grant numbers 70901066 and 71371173. Academic Technology Leaders of the Provincial Education Department of Henan Project under Grant number 2014GGJS-103.

Reference