Research Article

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The diffusion mechanism of the application of intelligent manufacturing in SMEs model based on cellular automata

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Abstract: Based on the characteristics of intelligent manufacturing and the theory of technology diffusion, this paper constructs a cellular automata model with government support policy, information exchange, technology maturity, diffusion intermediary, and market competition as the influencing factors and analyzes the influence mechanism of the first three main factors on the diffusion of intelligent manufacturing technology in industrial clusters using MATLAB. This paper also makes an empirical analysis of the diffusion of intelligent manufacturing technology in the bearing industry cluster in Xinchang County and finds that the results are basically consistent by comparing the simulation data with the fit degree of the real data. In this paper, the diffusion intermediary and government support policy have the greatest influence on the application of intelligent manufacturing in small- and medium-sized enterprises, and the model proposed in this paper is effective.

Keywords: industrial clusters, industrial dataspace, intelligent manufacturing, technology diffusion, cellular automata

1 Introduction

At present, the Internet of Things, 5G, cloud computing, artificial intelligence, and other new generation of information technology are booming and bringing new ideas to the development of China’s manufacturing industry. Whether small- and medium-sized enterprises (SMEs) can seize the opportunity of the vigorous development of intelligent technology and realize the intelligent transformation and upgrade, it will be related to the survival of SMEs in the fierce competition. Industrial cluster is the main model of the development of SMEs. Based on in-depth analysis of the technical and application characteristics of intelligent manufacturing and the reference to domestic and foreign technology diffusion model, this paper built a cellular automata (CA) model of the diffusion of intelligent manufacturing technology in industrial clusters, explored the impact of different factors on the diffusion of technology in industrial clusters mechanism, identified the factors that significantly affect the degree of diffusion, and verified that the model is reliable.

2 Literature reviews

In terms of the conditions of technology itself, Mansfield and Romeo suggested through empirical research that the superiority, investment intensity, and stability of new technologies had an impact on the diffusion of technology [1]. Rogres also believed that the nature of technology itself is one of the factors affecting the diffusion of technology and the speed of technology diffusion can almost be reflected in the testability, complexity, and comparative advantage of technology [2]. The lower the complexity and the greater the visibility and relative advantage, the faster the technology spreads.

As for the research on the technology diffusion mechanism within the industrial cluster, Lai and Shi
thought that the driving force of technology diffusion within the industrial cluster depends on the geographical environment, market environment, information service environment and policy, and regulatory environment within the cluster, which would affect the development of technology diffusion [3]. Feng and Li thought the industrial cluster technology diffusion of the driving factors include the internal factors and external factors of the cluster [4]. The internal factors include entrepreneurial quality, corporate culture, organizational structure, and operating conditions. The external factors mainly include the information service environment, policy environment, and social service environment of industrial clusters. Comin and Mestieri classified the power of diffusion into three categories: technical knowledge, aggregate needs, and policies [5]. Technical knowledge is reflected in the existing technological basis and human organization structure of enterprises. It determines the cost of new technology. Aggregate demand is the total amount of potential technology adopters in a cluster. Policies can maintain the technology benefits adopted by enterprises, reduce barriers to technology diffusion, and promote diffusion. When Ge was studying the technology diffusion mechanism in Zhejiang province's industrial cluster, he put forward that diffusion intermediary can play a regulatory role in the technology diffusion market, integrate resources, and build a communication platform [6]. Diffusion intermediary is an important factor affecting the diffusion of technology.

For the study of the environment aspect of industrial clusters, when Wang et al. studied the diffusion of new agricultural technologies, they proposed that the services, policy environment, and market environment of agricultural pushing institutions would have an impact on the diffusion of technology [7]. Among them, the market environment includes market demand and market structure. The greater the demand for agricultural products is beneficial to the diffusion of technology. By studying the cross-cutting diffusion model of new technological innovation, Luo et al. proposed that national policy guidelines, intellectual property protection, and local government support would all have an impact on technology diffusion [8].

Based on the theory of intelligent manufacturing and technology diffusion, this paper selects five influencing factors of the diffusion of intelligent manufacturing technology in industrial clusters from among the many factors mentioned above: diffusion intermediary, government support policy, information exchange, technology maturity, and market competition. By constructing the CA model of the diffusion of intelligent manufacturing technology in the industrial cluster, this paper made an empirical analysis of the diffusion of intelligent manufacturing technology in the Xinchang bearing industry cluster.

3 Modeling and the semantics of technology diffusion

This paper holds that technology diffusion is the emergence of new technology in a certain social system in a certain period of time. Members of the system receive information about new technologies, recognize and adopt new technologies, and then pass on new technical information to other member processes.

According to the characteristics of the diffusion of intelligent manufacturing technology in industrial clusters and some literature [9], the model based on this paper is constructed by reference to the improved cell automaton proposed by Guo et al. [10]. CA is a simulation model that is completely discrete in state, time, and space. The CA model generally consists of four elements: cell space, a collection of cell states, a combination of cells in all neighborhoods, and evolutionary rules for cell states.

In this paper, the construction idea of the diffusion model of intelligent manufacturing technology of SMEs in the cluster is as follows: an industrial cluster can be regarded as cell space and the size of the cluster can be equivalent to the size of cell space, and then it can consider the influence of various factors. The modeling process looks as follows:

First, cell and cell space. Assuming that the cell space is the whole system of diffusion of the technology and the cell range is the scope of industrial clusters. Each cell corresponds to a technology demander or owner, that is, for each enterprise.

Second, cell state. Establish state variables $S$ based on whether the enterprise has the willingness and ability to carry out intelligent transformation. Status $S = 0$ means ordinary enterprises, that is, enterprises that do not intend to carry out intelligent transformation. $S = 1$ indicates the potential implementation enterprise, that is, after receiving the relevant technical information, the enterprise has decided to introduce intelligent manufacturing technology. The enterprise is about to enter or is in the process of intelligent transformation. $S = 2$ indicates the implementation of enterprises, that is, enterprises have successfully carried out intelligent transformation and enterprise production, management models have cited digital technology, and enterprises have applied industrial Internet platform services.
Third, neighbor. This paper used the classic Moore-type neighborhood. The neighborhood defined here emphasizes the connection between various enterprises in the process of technology diffusion. A cell is neighbored with eight cells adjacent, and the state of each cell is updated by the neighbor’s influence.

Fourth, the rules of cell state evolution. The sum of the number of adjacent cells in the Moore-type neighborhood of the \((i, j)\) cell is represented by \(Q_{i,j}\), which is not changing over time. The sum of the number of adjacent cells of the \(t\)-moment \((i, j)\) cell in the “implemented enterprise” state is represented by \(T^t_{i,j}\).

(1) Evolutionary rules when the cell state is 0
First of all, when \(S^t_{i,j} = 0\), it indicates that at this time the cell state is ordinary enterprise. At this time, the cell state has two changes in direction, one is to continue to maintain the state of 0 and the other is to the potential implementation of the enterprise.

(a) The impact of entrepreneurial characteristics
In general, entrepreneur’s risk appetite can be divided into positive, conservative, and negative. Positive entrepreneurs refer to the decision-makers who will have a certain probability \((p)\) to enable enterprises to adopt intelligent manufacturing technology as long as there are a small number of neighbors around them. Under the influence of external factors, positive decision preference enterprises will also be the first to become potential implementing enterprises. Conservative entrepreneurs mean that decision makers who introduce technology will only be considered after the majority of their neighbors (presumably 50%) have adopted smart manufacturing technology, taking into account factors such as the cost of introducing technology and the certainty of benefits. Negative entrepreneurs have a more negative attitude toward intelligent manufacturing technology and are more reluctant to introduce smart manufacturing technology. It is assumed that the positive, conservative, and negative risk preference cells in the whole system are represented by \(x, y,\) and \(z\), respectively.

(b) The impact of market competition
Ordinary enterprises will also be affected by the cluster of market competition to change the state. Market competition comes from peer enterprises that have successfully introduced intelligent manufacturing technology. \(R\) is used to indicate the competitive intensity of market competition in industrial clusters. \(R^t_{i,j}\) is used to indicate the pressure coefficient of the \(t\)-moment \((i, j)\) cell under the influence of the cluster enterprise. \(c_i \ (i \in [0, 1])\) is used to indicate that the whole industry is the competitive pressure coefficient of the industry because of the changes in market demand and competition for resources. The value of \(c_i\) represents the size of the competitive pressure. Then:

\[
R^t_{i,j} = (T^t_{i,j} / Q_{i,j}) \times c_i.
\]  

(1)

When considering the competitive intensity of the enterprise competition in the cluster, each enterprise can withstand the pressure of \(r_{i,j}\). Because each enterprise is under different pressure, the \(r_{i,j}\) is set here belongs to the uniform distribution \((0, 1)\). The status update rules for cells under competitive intensity are as follows:

\[
S^t_{i,j} = \left\{ \begin{array}{ll}
0, & \text{if } R^t_{i,j} \leq r_{i,j} \\
1, & \text{if } R^t_{i,j} > r_{i,j}
\end{array} \right.
\]  

(2)

(2) Evolutionary rules when the cell state is 1
When \(S^t_{i,j} = 1\), it indicates that at this time the cell state is a potential implementation enterprise and the enterprise is willing to adopt intelligent manufacturing technology. If the transformation is not successful, then continue to maintain the original state of 1. If the transformation is successful, it becomes State 2.

The application of intelligent manufacturing technology in SMEs often has problems such as lack of free funds, lack of technical ability, and conflict of management mode; therefore, the success of the transformation is affected by the following factors: the status of enterprises’ own capital, government support policies, the development of intelligent manufacturing technology, the dissemination of information on industrial clusters, diffusion intermediary, and other factors. It can describe more objectively and accurately the phenomenon of technology diffusion of industrial clusters.

(a) The establishment of business conditions
Enterprise capital situation is better, can buy intelligent production equipment, and apply a variety of industrial and office software are the references to intelligent manufacturing technology based on the basis and premise. The specific formula is as follows:

\[
d_i = f(x_i) = \frac{1}{1 + e^{-x_i}},
\]  

(3)

where \(x_i\) indicates capital situation of enterprises in the cluster and obeys the normal distribution;
$d_i$ indicates the impact of the enterprise’s capital situation on the successful introduction of intelligent manufacturing technology, of which $f(x)$ is the general form of “growth curve,” in line with the general law of the development of things.

(b) Impact of information dissemination

Information dissemination comes from the knowledge spillover effect within the cluster. Information dissemination will bring about the diffusion of common knowledge, which is one of the most significant manifestations of external economy in technology system in industrial clusters.

$$d_2 = f(x_2) = \frac{1}{1 + e^{-x_2}},$$

where $x_2$ represents the dissemination of information between enterprises in the industrial cluster; $s$ represents the frequency of communication between enterprises in the industrial cluster, and it takes values between the values of 0, 1, and the higher the value, the higher the frequency of communication, the greater the diffusion of knowledge.

(c) Impact of the development of intelligent manufacturing technology

The maturity of intelligent manufacturing technology is one of the important factors that affect the time of intelligent transformation of enterprises and it has a positive correlation with the rate of success of enterprises adopting intelligent manufacturing technology. Enterprises from the decision to adopt intelligent manufacturing technology to complete the transformation takes a certain amount of time ($t$), assuming that the transformation of enterprises takes time to obey the uniform distribution of the “60, 150.” (The value of the interval selects the actual time of the intelligent transformation of SMEs in the research area.) The specific impact factor of the formula is as follows:

$$d_3 = t \times (1 - l),$$

where $d_3$ indicates the actual time required for intelligent transformation of enterprises; $l$ indicates the level of development of intelligent manufacturing technology, and it takes values between the values of 0, 1; $t$ indicates the time factor and increases as the number of simulations increases.

Under the premise of considering the above factors, consider the rate of success of the enterprise to carry out intelligent transformation. Setting the threshold $Y$ for successful transformation, the cell state becomes 1 point is $t_{ij}$, the government subsidy coefficient for enterprises is $c_2$, and the improvement of the supporting environment such as intermediary institutions in the industrial cluster is $m (m \in [0, 1])$. The specific state change formula is as follows:

$$S_{i,j}^{t+1} = \begin{cases} 2, & \text{if } (d_1 \times c_2 + d_3) \times m \geq Y \text{ and } t \\ \geq t_{i,j} + d_3, & \text{others.} \end{cases}$$

4 Simulation analysis and industrial case study

4.1 Discussion of the extent of the impact of the factors

According to the diffusion model of intelligent manufacturing technology in the cluster built in the previous chapter, MATLAB software is used for simulation analysis. To simulate the reality to the maximum extent, the three theoretical and most influential factors of government policy intensity, information dissemination, and intelligent manufacturing technology development were selected from five factors to study the specific impact of various factors on the diffusion of intelligent manufacturing technology in industrial clusters.

To make the model simulation better reflect the real situation, the initial parameters are stipulated below: The number of conservative enterprises will generally account for the majority of the total and the number of $y$-cell accounted for more than half of the total. As SMEs face appropriate competitive pressures, the value of $c_1$ should be around 0.5. The intelligent transformation of SMEs is still in an immature period. The government’s special policies, technology exchange and learning, technical maturity, and intermediary construction are not perfect, so the relevant parameters should be less than 0.5. The intelligent transformation of SMEs is more difficult, so the threshold $Y$ should be greater than 0.5. The probability of direct transformation of enterprises affected is relatively low, so parameter $p$ should be less than 0.5. The initial parameters are appropriately valued in accordance with the above provisions, as shown in Table 1.
4.1.1 Impact of diffusion intermediation

In this part of the experiment, the value of $m$ is 0.25, 0.40, 0.55, 0.70, and 0.85, respectively. Other parameters are set according to Table 1. The simulation results are shown in Figure 1.

As can be seen from Figure 1, the high diffusion intermediary participation is an essential factor for the diffusion of intelligent manufacturing technology in industrial clusters. The diffusion intermediary has the highest impact on the diffusion of intelligent manufacturing technology compared with other influencing factors. When the value of $m$ is 0.25 and 0.40, few SMEs are making intelligent transformations. When $m$ increases to 0.7 and 0.85, most of the enterprises in the cluster can use intelligent manufacturing and reach equilibrium in faster time. In summary, diffusion intermediary has a great influence on the application of intelligent manufacturing in SMEs and has a decisive effect on the diffusion of intelligent manufacturing technology.

4.1.2 Impact of the intensity of government support policies

In this part of the experiment, the value of $c_2$ is 0.25, 0.40, 0.55, 0.70, and 0.85, respectively. Other parameters are set according to Table 1. The simulation results are shown in Figure 2.

As can be seen in Figure 2, the strength of government support has a positive effect on the diffusion of intelligent manufacturing technology. The higher

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Table 1: Parameter value table

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Parameter initial value</th>
<th>Parameter description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>600</td>
<td>Cluster size: number of SMEs</td>
</tr>
<tr>
<td>$x:y:z$</td>
<td>1:3:1</td>
<td>The proportion of positive, conservative, negative decision-making enterprises</td>
</tr>
<tr>
<td>$q_1$</td>
<td>0.5</td>
<td>Competitive pressure coefficients in clusters</td>
</tr>
<tr>
<td>$q_2$</td>
<td>0.5</td>
<td>Subsidy coefficient of government support policy</td>
</tr>
<tr>
<td>$l$</td>
<td>0.3</td>
<td>Technology maturity rate, the degree to which industry standards are established</td>
</tr>
<tr>
<td>$s$</td>
<td>0.25</td>
<td>Exchange learning frequency among SMEs in clusters</td>
</tr>
<tr>
<td>$m$</td>
<td>0.5</td>
<td>Spread mediation within the cluster</td>
</tr>
<tr>
<td>$Y$</td>
<td>0.43</td>
<td>The threshold for enterprises to successfully apply intelligent manufacturing</td>
</tr>
<tr>
<td>$p$</td>
<td>0.05</td>
<td>Probability of active risk decision preference enterprises becoming potential implementing enterprises directly under external influence</td>
</tr>
</tbody>
</table>

Note: The selection of the value here is to illustrate the problem. When the parameter value is closer to 1, the greater the response of the corresponding parameter description, the smaller the other, under the scope, the middle value is generally taken.
government support policy is an essential factor for the diffusion of intelligent manufacturing technology in the cluster. When the policy support is low (when \( c_2 = 0.25 \)), the diffusion behavior will not occur. In summary, the government support efforts on the application of intelligent manufacturing of SMEs have a great impact and will not only improve the proportion of adoption when the equilibrium state but also determine whether the proliferation behavior occurs.

### 4.1.3 Impact of the dissemination of information

In this part of the experiment, the value of \( s \) is 0.05, 0.25, 0.45, 0.65, and 0.85, respectively. Other parameters are set according to Table 1. The specific simulation results are shown in Figure 3.

As can be seen in Figure 3, cluster information dissemination can improve the success rate of intelligent transformation of enterprises. When the value of \( s \) is 0.05, the diffusion reaches equilibrium in about 450 days, and the proportion of intelligent enterprises in the cluster reaches about 28.33%. When the \( s \) increases to 0.25, there was no significant change in the time for the diffusion to reach equilibrium, but the proportion of enterprises adopting intelligent manufacturing technologies increased significantly. Subsequently, when the \( s \) increases to 0.45, 0.65, and 0.85, the depth of diffusion increased significantly, but the diffusion speed did not change significantly. In summary, the impact of information dissemination on the application of intelligent manufacturing in SMEs is weak.

### 4.2 Simulation-based case study on intelligent manufacturing diffusion at Xinchang bearings industry

#### 4.2.1 Model parameter settings

Based on the above model, CA model (Figure 4), Xinchang mode (Figure 5), and some literature [11], this paper studies the diffusion of intelligent manufacturing technology applied by SMEs with Xinchang bearing cluster as the object. To make the cell automatic model show the real situation of diffusion in Xinchang bearing cluster to the greatest extent, this paper mainly considered the actual situation of Xinchang County and referred to the relevant literature when setting the parameters.

On the size of the business, according to the actual situation of enterprises in Xinchang bearing cluster, this paper sets 625 cells \((N)\). The proportion of the type of entrepreneur’s decision-making risk preference refers to the relevant literature. The decision-making enterprise of positive type, conservative type, and negative type decision-making enterprise ratio \((x:y:z)\) is 1:3:1. Competitive pressure coefficient \((c_1)\) referred relevant literature, set to 0.25. In the government’s support policy, this paper referred “The Xinchang County People’s Government issued a number of opinions on the overall promotion of the bearing industry transformation and upgrading,” its subsidy strength \((c_2)\) is 50%. In the technical maturity, Xinchang County Tuoman Intelligent Manufacturing Company put forward a replicable and can be promoted application standards, so this paper set \( l \) to 0.5. In the frequency of information exchange, the business exchange meeting and demonstration enterprise visit organized by the Xinchang County Government Association are less frequent, so the number of \( s \) is 0.25.

In the diffusion intermediary, the Zhejiang Intelligent Manufacturing Expert Committee as a provincial think
tank organization has set up a group of experts in the bearing industry in Xinchang County to provide advisory services and reform planning services to SMEs, so the value of \( m \) is 0.65. Both thresholds \( (Y) \) for successful application of intelligent manufacturing by enterprises and the probability \((p)\) of active risk decision-making preference for enterprises becoming potential implementing enterprises under external influence refer to the literature, take 0.75 and 0.1, respectively.

### 4.2.2 Simulation analysis

The number of cells sets in this simulation experiment is 625, and other parameters were also in accordance with the foregoing. The cluster enterprises were divided into three categories: ordinary enterprises, potential intelligent enterprises, and intelligent enterprises. The model would run 100 times, set the simulation data corresponding to the actual date and averaged all results, then took the number of intelligent enterprises in the cluster that have been transformed. Comparing the simulation data with the real data, as shown in Figure 6.

As can be seen in Figure 6, in the diffusion depth, the simulation results are in line with the actual situation. In 600 days or so, there are about 104 enterprises to adopt intelligent manufacturing technology. In terms of diffusion speed, the entire diffusion graph is also in line with the real situation.

The following is to fit the real data with the simulation data.

1. **Linear correlation analysis**

   Using SPSS to carry out linear correlation analysis of real data and simulation data on intelligent manufacturing technology diffusion, the data are shown in Figure 7. From Figure 7, we can see the significance of 0.000 far less than 0.010, so the real data of intelligent manufacturing technology diffusion in Xinchang bearing cluster are significantly related to the simulation data. The correlation coefficient is 0.997, close to 1, indicating that the real data of intelligent manufacturing technology diffusion are positively correlated with the simulation data.

2. **Symbol rank test results**

   The real data and simulation data of the diffusion of intelligent manufacturing technology in the Xinchang bearing cluster are tested by the symbolic rank test under...
the non-parameter test, and the test results are shown in Figure 8.

From Figure 8, it can be seen that the significance level of 0.766 is much greater than 0.050. According to the statistical principle, we can determine the real data and simulation data of the diffusion of intelligent manufacturing technology from the same overall data.

Through the linear correlation analysis and non-parameter test of Xinchang bearing cluster simulation data and real data, we can get the basic match of the real data and the simulation data, and the fit is very good. The cell automatic model has some practical significance.

5 Discussion

In this paper, the diffusion of intelligent manufacturing technology among SMEs in the bearing industry cluster in Xinchang County was the research object. This paper explored the main factors that can have an impact on diffusion and the effect of key factors on diffusion. To change the parameters in the CA model and carry out simulation experiments, we obtained the effect of diffusion intermediary, government support policy, information exchange, technology maturity, and market competition on diffusion and drew the factors with significant influence according to the simulation results. In view of the research on the application of intelligent manufacturing in the vast number of SMEs, the main conclusions obtained in this paper are as follows:

(1) The impact of key factors on the diffusion of intelligent manufacturing technology was analyzed through model building and computer simulation. The influence factor model of intelligent manufacturing technology diffusion in the bearing industry cluster of Xinchang County was constructed. The impact of five key elements on diffusion was explored through simulation analysis. Diffusion intermediary and government support policies have the greatest impact on diffusion. When the diffusion intermediary and government support policies for SMEs intelligent
transformation of the support are higher, the diffusion behavior of intelligent manufacturing technology in industrial clusters will occur. Information exchange also promotes the diffusion of intelligent manufacturing technologies, which have a positive impact on the speed and depth of proliferation.

(2) The “neighbor” in the cluster is an important factor that affects whether the decision-making of SMEs is intelligent. Using SPSS to compare the simulation data and the fit degree of the real data of the CA model, the results were basically consistent, and the model had achieved good simulation results. It is explained that the actual situation is similar to the influence of neighbors on the evolution of cell state in Moore-type CA machine and the application of intelligent manufacturing of SMEs in the bearing industry cluster in Xinchang County will also be affected by other enterprises in the cluster. On the contrary, the SMEs in the cluster will see the benefits of the application of intelligent manufacturing around enterprises and enhance the awareness of technological innovation. Ordinary enterprises will gradually change to potential implementation enterprises. On the contrary, with the gradual transformation of enterprises in the cluster, enterprises are gradually increasing the pressure of cluster specification, which will enhance the willingness of technology application. In addition, the dissemination of information will promote inter-enterprise exchange and learning. It also will improve the success rate of intelligent transformation of SMEs.

6 Conclusion

This paper constructed the diffusion model of intelligent manufacturing technology in the bearing industry cluster of Xinchang County based on CA and used simulation software to analyze the diffusion effect, such as diffusion intermediary, government support policy, technology maturity, information exchange, and market competition. Through empirical analysis, it was found that the real data and the degree of fit of the simulation data were consistent and the model had achieved good simulation results. This paper also obtained the above conclusions and the diffusion intermediary and government support policies on the application of intelligent manufacturing of SMEs had the greatest degree of conclusion. This will enrich the application field and related theories of the CA model and provide reference for other scholars to apply the model to study problems. The next step is to add more influencers to the model, set parameters more precisely, make the model closer to reality, and make the results more realistic for the simulation of the diffusion of intelligent manufacturing technology.

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