Ecosystem evolution mechanism of manufacturing service system driven by service providers

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To date, research has mainly discussed the definition and classification of producer services. Yet many companies require an integrated solution of products and producer services. The aim of this paper is to propose a model of the ecological evolution of manufacturing service systems (MSS) driven by service providers. This model adopts modular thinking to integrate dispersive producer services into an entire MSS, the process of which forms the ecological evolution of MSS. This paper applies ecological theory to build the ecological evolution mechanism of MSS. In this mechanism, the predator-prey relationship is used as a metaphor for the relationships between manufacturers and service providers in a MSS. A predator-prey model is built to simulate the ecological evolution of MSS. A predation cellular genetic algorithm is adopted to optimize this evolution. The proposed model and algorithm are demonstrated and validated by a case study of MSS in bicycle industry. This study contributes to theory by proposing and clarifying the mechanism for provision of services between businesses. The future research will focus on the application and empirical analysis of this mechanism derived from big data.

Keywords: Manufacturing service system; service providers; producer services; ecological evolution; predator-prey model.

1. Introduction

A manufacturing service system (MSS) is a system of producer services provided by service producers to manufacturers, for the purpose of maximally and most efficiently satisfying the production requirement of manufacturers. A MSS is usually supported by a set of specific protocols, the use of information technologies, and the integration of infrastructures. A MSS is composed of a number of integrated producer services in a network environment, in order to meet the requirement of specific production services. These services are set up by certain protocols and realized by using management systems and the completion of the service tasks (Tian et al. 2013). A MSS includes three components: service providers, manufacturers and end users. The manufacturers providers provide product-service systems (PSS) (Goedkoop et al. 1999) to the end users. The service providers provide producer services to the manufacturers. In this way, the three parts establish a network providing producer services or PSS to each other through a platform. The establishment of a MSS is an evolutionary process that the three parts interact with each other and achieve a balanced point. This paper investigates the dynamic evolutionary process of MSS and its evolution mechanism.

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The difference between producer services and PSS is that PSS emphasizes the integration of products and services offered to customers, the process in which additional value in use is captured (Baines et al. 2007); while MSS emphasizes the producer services provided from service providers to manufactures as part of the production of final products at the manufacturers' sites. PSS is the result of servitization (Neely et al. 2014; Benedettini et al. 2015; Kastalli et al. 2013; Turunen et al. 2014; Sarocha et al. 2012), and has been studied by a number of researchers (Tukker 2004; Piscicelli et al. 2015; Evans et al. 2007; Yang et al. 2013; Durugbo et al. 2011; Szwejczewski 2015; Christopher 2013). The current study in the field of MSS is not yet mature. The combination of producer services (Radnor et al. 2014; Agya et al. 2014; Lindahl et al. 2014;) and PSS (Mont et al. 2002; Jiang et al. 2011; Long et al. 2013) need to be achieved through information technologies, service-embedded manufacturing (Sun et al. 2007; An et al. 2015), cloud manufacturing (Li et al. 2010; Yang et al. 2014; Lartigauet al. 2015), internet of manufacturing things (Yao et al. 2014; Hou et al. 2014; Zhang et al. 2014) and maintenance operation system (Ge et al. 2009; Wang et al. 2010) MSS involves the complex relationship between the service providers, manufacturers and the end users. There is a need to study the mechanism of the evolution of a MSS built by the three parts. This paper studies the evolution of a MSS from the perspectives of service providers and manufactures, and builds the mechanism of MSS evolution driven by service providers.

This paper proposes to use a predator-prey relationship can be used to describe the relationship between service providers and manufacturers. Predator-prey relationship is the basic relationship of interaction between species in nature. A number of optimization algorithms are built from the simulation of ecological predator-prey model. Li et al (Li. 2003) developed an advanced multi-objective optimization algorithm based on the predator-prey mechanism. This algorism can simulate the dynamic change of the size of prey population caused by the change of space. This is achieved through hybrid crossover operator to implement an adaptive search. Deb and Bhashara (Deb et al. 2005) improved the selection strategy of genetic algorithm according to the predator strategy in nature. Jiang et.al (Jiang et al. 2007) proposed a predator strategy, which can achieve a local or global search by controlling the size of the search space. This strategy together with the genetic algorithm has been used to solve the vehicle routing problem. Manderick and Spiessens (Manderick et al. 1989) proposed a cellular genetic algorithm at first, based on which, Kirley (Kirley. 2002) developed a cellular genetic algorithm with cycle reckoning function to simulate the space interaction in nature. Simoncini (Simoncini et al. 2006) then proposed a selection mechanism to improve the diversity of cellular genetic algorithm, which can control the pressure of the population selection. Janson and Alba (Janson et al. 2006) developed a kind of hierarchical cellular genetic algorithm, which can fit the individuals from a population in a cellular space orderly.

This paper uses the predator-prey relationship as metaphor for the relationships between the three parts of a MSS, and adopts cellular genetic algorithm to simulate the evolution mechanism of MSS driven by service provider. This evolution mechanism can achieve a dynamic optimization of manufacturing service relationship.

2. Literature review

2.1 Producer services

Producer Services are the manufacturing-services relations arising between the service and manufacturing enterprises, providing intermediate products or services by which the manufacturing enterprises to produce the end-products or serve for manufacturing. (Zhang et al.2016).

The concept of producer services was first proposed by the American economist Greenfield in 1966, in order to study the service industry and its classification (Greenfield. 1966). He emphasized that the producer services provide services for production and business activities, and that these features are referred to as intermediate inputs, which do not include the ultimate consumers. Then for the classification of service industry, Ilber and Healey proposed classification concept of service industry is divided into consumer services and producer services (Healey et al. 1990). The concept that producer services to other companies to provide services by Howells and Green (Howells et al. 1986).

The producer services can improve the output value and movement efficiency during the production phases (Hansen. 1993), including office cleaning, goods storage and allocations, scientific services, etc (Healey et al. 1990). Flexible working raised by Coffey and Bailly is for studying the relations between the increase in producer services and zones (Coffey et al. 1991). Harrington et al. (1995) proposes that the British producer services also contain information and technology services, employment boosting relevant services, etc, which confirms one of the producer services: manufacturing information services (Hepworth et al. 1989), providing intermediate products for manufacturers. Goe et al. (1990) considers the manufacturing enterprises as the main targets for the producer services.. In recent years, the producer services has provided essential support for the manufacturing industry in the integration of manufacturing and services (Yao et al. 2015; Lanaspa et al. 2016) as well as the important subjects for the manufacturing services research.

2.2 Servitization of manufacturing

The servitization of manufacturing is a relation between the manufacturing enterprises and the end-users. The manufacturers are constantly improving the services characteristics of their products to meet the individual requirements of the end users, finally forming the product-services systems. (Zhang et al.2016).

The servitization of manufacturing is to study whether the service proportion is rising in the manufacturing industry. The concept of the shift from goods to services, first raised by Becker in 1962, can be regarded as the origin of the servitization of manufacturing, afterwards some scholars proposed the concepts of the non-industrialization (Karldo et al. 1966), post-industrial society, service economy, etc. Meanwhile many scholars have found that the manufacturing industry is servitizing in surveying the importance of the manufacturing industry (Carson et al. 1998; GarciaMila et al. 1998; Drucker et al. 1990). Since 1980s, the servitization of manufacturing research mainly focuses on two aspects: one is to discuss the trend of servitization in the manufacturing industry (Vanderemerwe et al. 1988), and define servitization as providing solutions for the manufacturing firms in form of goods services package, through which the manufacturers can creae added value; the other is to study the relations between the servitization and the environment (White et al. 1999), defining it as a dynamic process during which the manufacturers change their role from the product providers to service providers; In 2003, Szalavetz proposed that the services to the total manufacturing input ratio were increasing (Szalavetz et al. 2003). He regarded it as the manufacturers' competitiveness, including the manufacturing efficiency and the effective provision of the internal services, meanwhile the external services were becoming more important.

Neely and his team have qualitatively studied the relevant issues on the servitization of manufacturing, such as service-oriented business model innovation, value creation through servitizaiton, service complexity, and service performance (Neely et al. 1999) (Adrian et al. 2009; Ornella et al. 2015). This work leads the international research on the servitization of manufacturing.

2.3 Product-service systems

Product-service systems (PSS) is commonly regarded as the integration of products and services provided by manufacturers to end users (Manzini et al. 2003; Morelli et al. 2006). PSS is a novel production system of highly integration of products and services and overall optimization in the entire life cycle of the product service model under the product manufacturers. PSS can include product-oriented PSS, use-oriented PSS, and result-oriented PSS (Tukker, 2004).

Evans and his team mainly studied the sustainability potential of product-service systems (Evans et al. 2007; Evans et al., in press), such as sustainable solutions in production-consumption systems (Partidario et al. 2007), sustainable value analysis for PSS (Yang, 2015), using value uncaptured perspective for sustainable PSS innovation (Yang et.al., 2017), and manufacturing framework for capability-based PSS design (Gokula et al. 2013). Some of the work has been developed into methods and tools for practical use in industries, such as Sustainable Value Analysis Tool (Yang et al. 2014).

Gu et al. (2009) proposed the key generic technologies of the product-service systems by case studies in the manufacturing service practice in multiple industries, such as steam turbine and household. It does not only include the technologies of product service oriented design, product repair services, product service oriented user demands mining, product service humanization, product service information collecting, but also the theories on product service system organization and process optimization, the theories and methods of the whole life cycle management of the product services. Jiang et al. (2011) has given a detailed definition of the Industrial Product Service System (IPSS) and its execution logic and its classifying methods, and the key technologies of the IPSS, mainly including IPSS production capacity modelling, IPSS operation model and process modelling, value analysis of the IPSS service, etc.

3. Ecological evolution model of manufacturing service system driven by service provider

3.1 Manufacturing service system

Manufacturing Service System is an information system by the integration and evolution of manufacturing service modules, which satisfies the needs of the service subjects, providing complete solutions, and transforming the manufacturing service modules into manufacturing service systems based on the solutions. (Zhang et al. 2016). A MSS includes three parts: service providers, manufacturers and end users. The service providers provide production-related services to the manufacturers as part of the production for their final products/services (termed producer services), and the manufacturers provide the final products/services to the end users. The ecological evolution of MSS is the evolution of the ecology-based interdependent relationship of producer services between the three parts in a MSS. This paper focuses on the producer service relationship driven by service providers, and aims to build the ecological evolution of the predator-prey relationship between manufacturers and service providers. MSS is an open, complex system, in which the manufacturers, service providers and end users exchange material, energy, information, knowledge, technology and money between each other, forming a self-organized and self-adaptive ecological unit with certain functions.

With the advent of Internet and information technology, the boundary of value chain becomes blurred. The relationship between firms becomes more complex and the value chain evolves into a value network. Value network shows the value exchange among the companies along a value chain. The companies integrate with each other dynamically, and form topological space and value flow. In a MSS, a value network comprises of a number of interconnected, interdepended manufacturing service modules. The relationships between the modules are resulted from the activities along value chain, including value creation, value delivery, value distribution and value use. Internet plays an important role in a modern MSS. In an Internet environment, the focal firm interacts with other firms, such as service providers, manufacturers, end users, competitors, and complementary firms (see Figure 1). There is value flow between the service providers, the manufacturers and the end users.

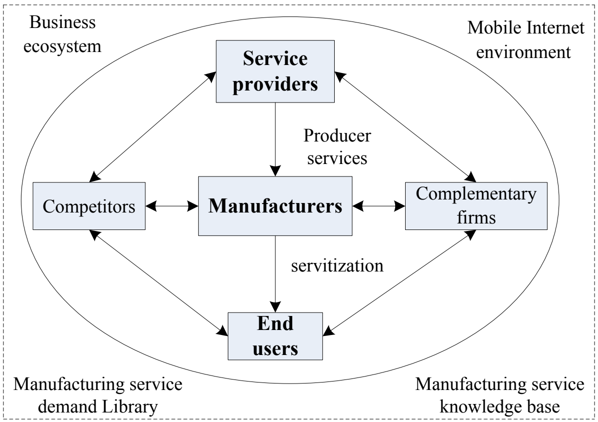

Fig. 1 The structure of a MSS

In an Internet environment, a node firm or a manufacturing service module could have the functions of product development, procurement, production, marketing and services, but it does not fully achieve these functions. Each node firm only provides the function with its most competitive part in the value flow while virtualize other functions by integrating external resources. The rapidly changing Internet environment forces firms to interconnect with each other in a fierce market competition, and thus build a value network of a MSS. In this value network, each node represents an organization, such as service provider, manufacturer, end user, complementary firm and competitor. In the value network of a MSS, the relationships include three types: vertical, horizontal and oblique. It should be noted that the boundary of a MSS may be blurred and permeable, and each node many be interdependent to each other. This could help with the flow of information across time, space and the boundary of nodes, and thus improves the system's adaption to the environment.

In the context of Industrial 4.0, the manufacturing service system rests on the operation of the manufacturing service platforms featuring networking and information technologies, providing not only mobile internet environment, business ecosystem, knowledge-based inference system, etc, but also the big data analysis to support the coordination and the decision making of the manufacturing service system.

The product service system is a system about the products and services that the enterprises provide for users without distinguishing the service enterprises, manufacturing enterprises and end users. This paper separates them to study the producer services and the servitization of manufacturing. The manufacturing service system can be in the relations between the services and the manufacturing enterprises, or between the manufacturing enterprises and the end users. This paper only discusses the evolutionary mechanisms of the manufacturing service system generated between the service and the manufacturing enterprises, without considering the relations between the manufacturing enterprises and the end users which will be discussed in another paper due to their different evolutionary mechanisms.

3.2 The ecological evolution process of manufacturing service system

The ecological evolution of MSS is a life cycle process including five stages: generation, extension, coordination, development and regeneration (Zhang et al. 2016). The concept of evolution previously refers to the biological development in the nature, and now has been applied in management field to represent the development of companies due to their similarities in terms of change. MSS is an open, complex and self-adaptive system with both biological and social characteristics. Due to the dynamic change of markets and technologies, the ecological evolution of MSS is influenced not only by the interaction of its internal factors but also external factors embedded in the evolutionary history. This forms different pathways of evolution. In enterprise life cycle theory, a company is viewed as a creature and its development is compared to the process of a creature from its birth to death. The life cycle theory in nature can be used to explain the growth and aging of firms, as well as MSSs. Therefore, MSS can be regarded as a creature and the theory of life cycle in nature can be used to analyse the ecological evolution process of the MSS.

In this paper, we investigate the ecological evolution driven by service providers. The mechanism of predator-prey model is based on the service providers – the manufacturers prey on service providers. In this way, the personalized MSS is built.

(1) The generation of MSS

Service providers provide producer services. On the one hand, service providers turn their resource into producer services, and upload it into Internet, waiting for manufactures' predation. On the other hand, service providers seek for the producer services requirement of the existing manufactures, in order to design new producer services to fulfill the requirement. MSSs network between manufactures and service providers is built, and the stability of the network is analysed by predator-prey model. For some specific manufactures, the specific manufacturing service solutions are set according to the specific needs.

(2) The extension of MSS

The ecological niche of service providers for specific manufactures is determined and matched. The general producer services are personalized transformed. Then, multiple primary schemes can be determined in the manufactures thought their communications, and the comparison mechanism of schemes is built. The typical configuration and performance parameters of similar producer services can be introduced for manufactures to make choices. This is also helpful for similar service providers to compare related information.

(3) The coordination of MSS

The coordination stage is a negotiation process that reaches a preliminary service agreement between manufactures and service producers in terms of the service mode, price, time, etc. This stage is based on the comparison of solutions and focused on a specific producer service. The service providers should provide preys actively, and the manufactures can design different MSS schemes according to the producer services.

(4) The development of MSS

In manufacturing service network, service providers drive the development of MSS, and actively adapt to the manufactures' predation. Manufactures turn the producer service requirement into specific parameters, use the predation cellular genetic algorithm to prey on the producer services from the lowest MSS schemes. Then, the performance of MSS is tested through market adaptation, and the MSS is dynamically optimized, in order to achieve an optimal MSS.

(5) The regeneration of MSS

It is assumed that service providers do not update producer services if this is not required by manufactures. When manufacturers propose new requirement, the MSS start to update functions, develop new producer services, and satisfy new service requirement through the restructure of the producer services. In this way, new MSS is generated and starts to provide producer service in its own life cycle.

3.3 The predator-prey model of ecological evolution of manufacturing service system driven by service providers

In a MSS, the service provider provides intermediary services to manufacturer for the production of other products. This paper propose that the service relationship between the service provider and the manufacturer can be explained by the relationship between predator and prey in nature, and that Lotka-Volterra, a predator-prey model, can be used to describe and simulate the evolution mechanism of this relationship.

Predator-prey relationship happens when one creature feeds on another, such as predators eating herbivores animals, herbivorous animals eating green plants, parasites and insects in the cannibalism. There are three simplified assumptions in Lotka-Volterra predation model. First, there is only one predator and one prey in each relationship. Second, if the population of predators fall below a certain threshold, the population of prey will rise; while if the population of predators increases, the population of prey will decline. Third, if the population of prey arises to a certain threshold, the predator population will increase; the population of predator declines when the prey population reduces.

The service provider can be regarded as a predator, and the manufacturer as a prey. The ecological evolution of MSS driven by service provider is shown in Figure 2. For example, F1 - F2 - F5 - Z1 form a MSS that is driven by service provider, and the relationship between them is linked through producer service. The ecological evolution of MSS can be seen as an evolutionary process that service provider prey manufacturer, and finally achieve to a state of MS2 - MS3 - MS5 - MS6 - MS12 - Z1.

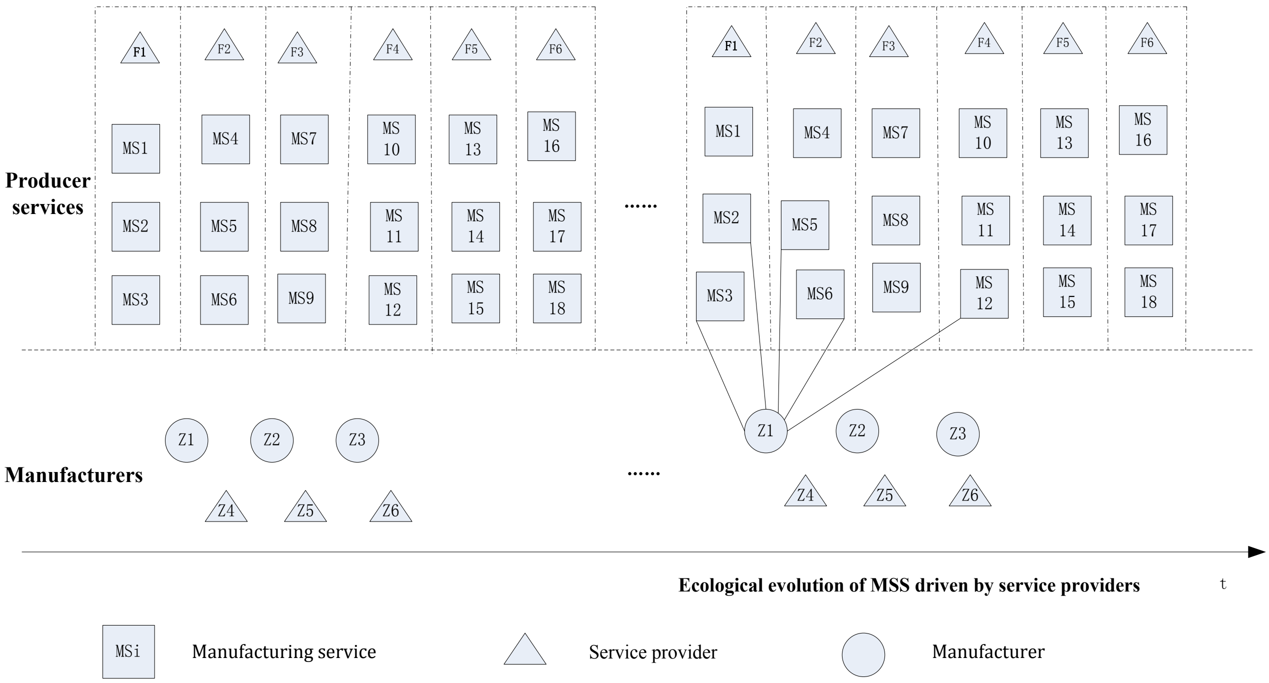

Fig. 2 Ecological evolution of MSS driven by service provider

In a simplified situation, the act of manufacturers purchasing producer services from service providers leads to the reduction of inventory of service providers. We view this act as the interaction between predators and preys, and that the ecological predator-prey models can be used to study the relationship between service providers and manufacturers.

Assuming that there is only one service provider and one manufacture in a MSS. Within a limited system K, if there is no manufacturer buying producer services from the service provider, the inventory of producer services y_2 shows the a logistic growth:

$$\frac{dy_2}{dt} = r_2 y_2 \left(1 - \frac{y_2}{K}\right) - q y_1 y_2 \qquad (1)$$

In formula (1), y_2 represents the inventory of service providers, t represents the time, r_2 represents the biggest growth rate of output of service providers, K represents the maximum producer service module that the environment can hold, y_1 represents the output of manufacturers, and r_1 represents the maximum growth rate of the output of manufacturers. It is assumed that the output will be reduced in geometric series under the circumstance that no service provider producer services.

$$\frac{dy_1}{dt} = -\mathrm{r}_1 y_1 \qquad (2)$$

When the service provider and manufacturer exist in one system, the predator-prey model between them is established as follows.

$$\frac{dy_2}{dt} = r_2 y_2 \left(1 - \frac{y_2}{K}\right) - q y_1 y_2 \qquad (3)$$

In formula (3), q is the purchase rate, the rate that manufacturer buys services from service provider. It is assumed that the output of manufacturer is increased with the increase of the production of the service provider.

Therefore, the predator-prey model for manufacturer can be built as follows.

$$\frac{dy_1}{dt} = \left(-r_1 + \theta q y_2\right) y_1 \qquad (4)$$

In formula (5), θ is the efficiency of using the producer services as part of the production of the final products in manufacturer. Formula (2) and (3) described the services relationship between manufacturer and service provider within a MSS. According to this model, the fewer purchases of producer services, the higher the service inventories at service providers become. The production of manufacturer is reduced if the service provider does not provide enough producer services. When the producer services just meet the needs of manufacturers' demand without increasing inventory, it reaches a balance that Formulas (3) and (4) are equal to each other, as follow.

$$\frac{dy_2}{dt} = \left(-r_1 + \theta q y_2\right) y_1 = 0 \qquad (5)$$

Therefore, the zero inventory growth of service provider can be represented as follows.

$$y_1 = \frac{r_2}{q}\left(1 - \frac{y_2}{K}\right) \qquad (6)$$

Likewise, the zero growth of the manufacturer's products is:

$$y_2 = \frac{r_1}{q\theta} \qquad (7)$$

The intersection of the lines y_1 and y_2 lines represents the point when service providers' inventory and manufacturers' production scale reach a stable state. It is coordinates is:

$$\frac{r_1}{q\theta}, \frac{r_2}{q} - \frac{r_1 r_2}{\theta K q^2} \qquad (8)$$

Therefore, the condition that service provider and manufacturer achieve equilibrium is:

$$\frac{r_2}{q} - \frac{r_1 r_2}{\theta K q^2} > 0 \qquad (9)$$

which is

$$q\theta > \frac{r_1}{K} \qquad (10)$$

4. The principle of ecological evolution of manufacturing service system based on predator-prey relation

In this paper, the relationship between service provider and manufacturer in a MSS are compared to the predator-prey relationship in the nature. This relationship is the foundation for the ecological evolution of MSS, based on which the principle of this ecological evolution is built.

4.1 The predator-prey relationship between service provider and manufacturer

This paper uses ecology model to simulate the ecological evolution of MSS. The ecological evolution of MSS driven by service provider is dependent on the mechanism of the predator-prey relationship. This relationship is one of the most basic relationships reflecting the survival and death competition in the nature. Different species are contradictory and interdependent following the mechanism of predator and prey. The predators and preys are under pressure from the each other. The predators need to improve their skills of the hunt, while the preys need to enhance its ability to protect them. Predator-prey relationships are helpful to the evolution of both predators and preys. It is found that the individuals under predator-prey relationships usually have better ability to adapt environment.

The predator-prey model can be used to explain the mechanism of the ecological evolution driven by service providers. Its ecological benefits mainly contain four aspects: 1) Manufacturers play a significant role in managing the resource flow in a MSS. There are cases of prey actions in each stage of the evolution. 2) Manufacturers can effectively adjust the dynamic of the service providers' populations. 3) Manufacturer plays an important role in maintaining the fitness of service providers, for example, manufacturer tends to prey on the service provider with high fitness. 4) Manufacturer can select the key factors as the conditions of the evolvement of service providers.

As mentioned earlier, the condition that the service provider and manufacturer achieving equilibrium is $q\theta > \frac{r_1}{K}$. This means, when the efficiency of converting the producer services into the final products, multiplied by the purchase rate of production services are large enough, the service relationship can reach equilibrium. Therefore, improving the conversion efficiency of production services and the purchase rate can help both manufacture and service provider to reach equilibrium.

(1) The analysis of θ: If θ increases, which means the conversion efficiency increases, the inventory of producer services will reduce at equilibrium point, and then the output scale of the final products in manufactures will increases. This scenario is good for both manufactures and service providers. On the contrary, if θ decreases, it is harmful to them. Thus, the improvement of the conversion efficiency is beneficial to the entire MSS.

(2) The analysis of q: The inventory of producer services at equilibrium point and the value of q have an inverse relationship. However, the output scale in manufactures and q have the relationship of a parabola pointing downward, plotted by q on the horizontal axis and the output scale in manufacturers on the vertical. In this parabola, there is an optimal purchase rate of producer services, which enables the largest output scale for manufacturers. When the purchase rate is less than optimal value, the output level would increase with the increase of the purchase rate, which is also beneficial to service providers. Therefore, when the purchase rate is less than the optimal value, the increase of purchase rate is beneficial to the entire MSS; and when the purchase rate is larger than the optimal value, the increase of purchase rate is not necessarily good to the MSS. This means, in a MSS with limited resource, manufacturers should not be too dependent on service providers.

Based on the analysis above, this paper proposes the service relationship model between manufactures and service providers. In a MSS of limited environment, the improvement of conversion efficiency (the efficiency of turning producer services into part of final products) and purchase rate (the rate that manufactures buy producer services from service providers) can help manufactures and service providers reach equilibrium. When the purchase rate is less than the optimal value, the increase of purchase rate is beneficial to the entire MSS; and when the purchase rate is larger than the optimal value, the increase of purchase rate is not necessarily good to the MSS. Therefore, in a MSS with limited resource, manufacturers should not be too dependent on service providers, and the service relationship can bring mutual beneficial to manufactures and service providers.

4.2 Predation cellular genetic algorithm based on the service provider and manufacturer

This section uses the cellular genetic algorithm to simulate predator-prey relationships, and to achieve the dynamic optimization of MSS. Firstly, the predation operation model between the population of manufactures and service providers is built based on the theory of cellular automata. Secondly, the predation cellular genetic algorithm is used to simulate the act of manufacturers preying on producer services from service providers. Finally, this algorithm is used to optimize the MSS, with the fitness of market as the optimization goal.

(1) Basic concepts

A standard cellular automata is composed of the following elements: cellular automata, cellular space, neighbours and rules. Its mathematical expression is $A = (L_d, S, N_d, f)$. In this formula, A represents the cellular automata. L_d represents the cellular space with d as the dimension. S represents the status of cellular automata, i.e. 'alive' or 'dead'. N_d represents the structure of neighbour. If the neighbour structure is Moore type, the neighbour scale is larger than one, i.e. $|N_d| \geq 1$, and there is at least one cellular is adjacent to the central cellular. F represents the evolution rules, which can transform the status of the central cellular according to the status of the neighbouring cellular.

In a predator-prey model, the populations of predator (manufactures) and prey (service providers) are placed in two cellular space with the same structure, as is shown in Figure 3. Manufactures prey on service providers. The black circles represent the live predator individuals, and the grey circles represent the dead ones. The black boxes represent the live prey individuals, and the grey boxes represent the dead ones. The nine cellular within the thick lined boxes are the central cellular and the neighbouring cellular.

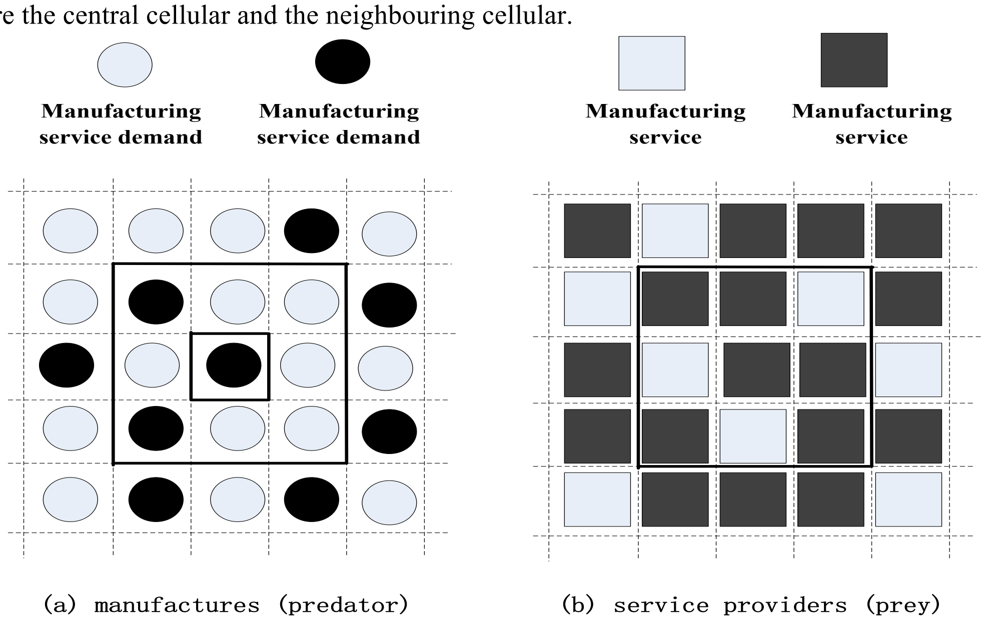

Fig. 3 The manufactures and service providers in cellular space

In this model, the predator's predation ability and the prey's service capability are associated with the adaptive value of the individual. The predator and prey individuals with high adaptive value have stronger abilities of predation and service. The distribution function of the adaptive value dependent predation ability and service capability is has ridge shape:

$$p(x) = \frac{1}{2} + \frac{1}{2}\sin\left(\frac{\pi}{f_{\max} - f_{\min}}\left(f(x) - \frac{f_{\max} + f_{\min}}{2}\right)\right) \quad (11)$$

In formula (11), $p(x)$ presents the predation ability or the service capability of the individual x. $f(x)$ represents the adaptation of the individual x. $f_{\max}$ and $f_{\min}$ present the maximum and minimum adaptive values of the individual x in a population.

In a predation operation, the predator individual can only prey on the neighbouring individuals, as is shown in Figure 4. For example, the live predator X, the black circle in Figure 4 (a), can only prey on its relating neighbouring preys shown in Figure 4 (a), the picture on the right. A predation operation happens if the service capability of the neighbouring preys is larger than the predation ability of the predator X, as is shown in Figure 4 (b). The predator X usually preys on the prey with largest service capability, and then moves to the cellular of the dead prey. However, if the predation operation fails, the predator X become dead and its circle becomes grey, as is shown in Figure 4 (c). In this predator-prey model, the individuals with low survival abilities (i.e. predation or escape abilities) die out due to the predation operations, and the ones with strong survival abilities survive and reproduce.

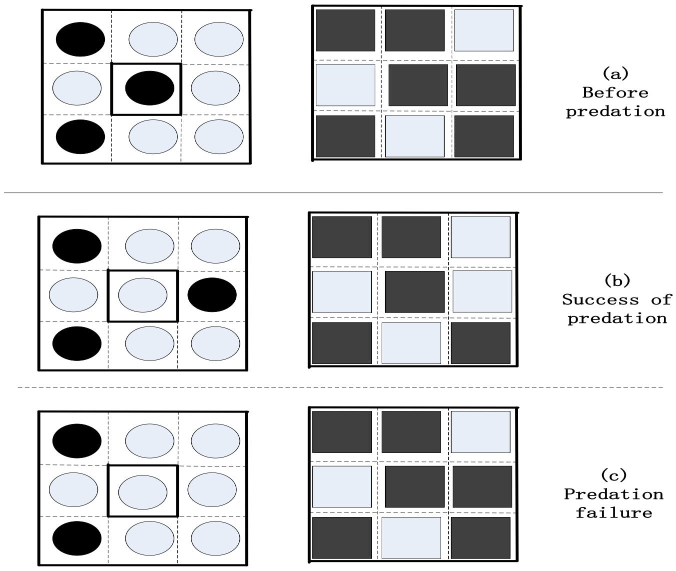

Fig.4 The predation operations between predators (manufactures) and preys (service providers)

(2) Predation cellular genetic algorithm

Predation cellular genetic algorithm is based on the cellular automata genetic algorithm, and is tailored to simulate the predation relationship between two populations. This algorithm integrates the predator-prey model and population control strategy into cellular automata genetic algorithm, and considers the population control and the orthogonal crossover operator (Chen et al. 2012). In this way, the survival status (i.e. alive or dead) of individuals can be determined based on the predation model, and the size of a new generation can be determined based on the population control mode. Therefore, this algorism builds a predator-prey model within cellular space according to the predator-prey relationship in the nature. In this model, the size of the population is self-adapted, and the evolution rules are naturally established because of the evolution of the predation operations. The flowchart of the predation cellular genetic algorithm is shown as follows.

begin

Initializing the predator population (i.e. manufactures) $P_1(0)$ and the prey population (i.e. service provider) $P_2(0)$.

Locating the individuals of $P_1(0)$ and $P_2(0)$ in cellular space, and initializing the survival status (alive or dead)

repeat

Adaptive value calculation:

$$f_1 = evaluate(P_1(t)),\quad f_2 = evaluate(P_2(t))$$

Predation capacity calculation:

$$Fit_1 = normlize(f_1)$$

Service capability calculation:

$Fit_2 = normlize(f_2)$ // predator - prey model

Predation operation:

$(P_1^{'}(t), P_2^{'}(t)) = \Pr edatoryOperator(P_1(t), P_2(t))$Population control:

$(|P_1(t+1)|, |P_2(t+1)|) = POpControl(|P_1^{'}(t)|, |P_2^{'}(t)|)\; P_1(t+1) = \lfloor P_1^{'}(t), |P_1(t+1)| - |P_1^{'}(t)| \text{Random individual} \rfloor$

if $|P_2(t+1)| > |P_2^{'}(t)|$ **then**

$P_2(t+1) = \lfloor P_2^{'}(t), |P_2(t+1)| - |P_2^{'}(t)| \text{Random individual} \rfloor$

else the optimal individuals $|P_2^{'}(t)|$ within $P_2(t+1) = P_2^{'}(t)$ // genetic operations

for each alive individual I_i, choose the optimal individuals $I_i^{'}$ from its neighbours N_i

$offspring = crossover(\lfloor I_i \quad I_i^{'} \rfloor, p_c)$// Algorism: Predator-prey Cellular Genetic Algorithm

$offspring = o - crossover(\lfloor I_i \quad I_i^{'} \rfloor, p_c)$// Algorism: Improved Predator-prey Cellular Genetic Algorithm

$offspring = mutate(offspring, p_m)$

$f_{offspring} = evaluate(offspring)$

if $\min(f_{offspring}) < f(I_i)$ **then**

Replace I_i with the optimal individuals in $offspring$

end for

until $ter\min ated = true$

end

4.3 Dynamic optimization of manufacturing service system based on the predation cellular genetic algorithm

The MSSs layers evolve according to the ecological evolution rules, generating a manufacturing service network. The result of the ecological evolution needs to be tested in terms of market adaptation before entering a further layer of MSS. The cellular genetic algorithm can be used to simulate the test of evolution degree plans and the process of the plans entering into another layer. The specific steps are as follows:

（1）The gene attributes of the producer services in service providers can described in the format of multiple groups. For example, the gene attributes of the producer service A can be described as $GA = \{A_1, A_2, \ldots, A_N\}$. In this, A_1, A_2 can represent the price and quality of the producer service A. The same set of attributes can represent the same type of producer services. The different value represents the different producer services of the same type.

（2）The producer services requirements from manufactures can be represented as : $CR = \{cr_1, cr_2, \ldots, cr_n\}$. Then, the groups of producer services and the related requirements can be mapped and compared. Different types, such as numbers, words and multistage can be used to do the map (Wang et al. 2004; Zhou et al. 2007).

（3） Calculating the adaptation of MSS plans

Before calculation, the original data is transformed linearly and mapped into the values range of [0, 1]. The linear transformation function is called normalized function, and the expression is:

$$X' = \frac{X - f_{\min}}{f_{\max} - f_{\min}} \qquad (12)$$

In the formula: x is the original value of the property f ; $x^{'}$ is the value of the converted value; $f_{\min}$ and $f_{\max}$ are the minimum and the maximum of the value of the attribute. The selection of fitness function directly determines the evolution direction of the MSS and the evolutionary result. The fitness function is defined as the universal and adaptive fitness function:

$$Fix(x_i, y_i) = 1 - |x_i - y_i| \tag{13}$$

$$Fix(x, y) = \frac{\sum_{i=1}^{n} w_i Fix(x_i, y_i)}{\sum_{i=1}^{n} w_i} \tag{14}$$

In the formula, x , y are the value of the producer services in the gene set and the market demand; x_i , y_i are the value of the producer services attributes i and y in the gene set and the market demand concentration; w_i is the weight of the attributes; $Fix(x, y)$ is the fitness for the manufacturing service; $Fix(x_i, y_i)$ is the fitness for the of the attributes.

（4）Population replacement: the plans with low adaptation and evolution capabilities are introduced as 'rogue' into symbiotic elements in order to improve its adaptation and generate new MSS plans with the same size.

（5） Internal ecological evolution: using predation cellular genetic algorithm to generate MSS schemes. These schemes are following T type internal ecological evolution.

（6）Convergence determination. The scheme is die out if it does not achieve convergence, otherwise（7）

（7）End of algorithm. The manufacture service system enters a higher layer.

5. A case of ecological evolution driven by service providers in a bicycle manufacturer

To Manufacturing service platform is the main media for the ecological evolution of MSS. On this platform, the producer service relationship is built between manufactures and service providers. This paper uses bicycle production in a region as an industrial case to illustrate the ecological evolution of MSS and explain the mechanism of the ecological evolution.

The bicycle manufacturing service system is raised as a case, and the core enterprises are the bicycle manufacturing enterprises and the several supporting enterprise are the bicycle service enterprises. The service enterprises promote the evolution of the bicycle manufacturing service system through upgrading their competitiveness, meanwhile the manufacturing enterprises will select the manufacturing services from the service enterprises by cellular genetic algorithm based on predator-prey mechanisms and test the market fitness to dynamically optimize the evolutionary process, finally construct the bicycle manufacturing service system.

The producer services (Tian et al. 2013) are shown in Table 1. $MS_{ij}(PR, QU, SE)$ represents the producer service j provided by the bicycle service provider i . PR is the price of the producer service (with the unit Yuan); QU is the quality of the service, and the number represents the level of the service quality: 1 (lowest), 2 (junior), 3 (intermediate), 4 (advanced), 5 (highest). SE is the producer service, and the number represents the types of the services: 0 (no service), 1 (maintenance), 2 (financial services).

Table 1. The producer service provided in a regional bicycle service provider

Bicycle **service provider**	$MS_{ij}(PR, QU, SE)$				
F1 Guidance system	MS11（100,1,0）	MS12（150,2,0）	MS13（200,3,0）	MS14（250,4,0）	MS15（300,5,0）
F2 Drive system	MS21（100,1,0）	MS22（150,2,0）	MS23（200,3,0）	MS24（250,4,0）	MS25（300,5,0）
F3 Brake system	MS31（60,1,0）	MS32（80,2,0）	MS33（100,3,0）	MS34（120,4,0）	MS35（140,5,0）
F4 Auxiliary device	MS41（300,1,0）	MS42（400,2,0）	MS43（500,3,0）	MS44（600,4,0）	MS45（700,5,0）
F5Personalitycustomization	MS51（300,1,0）	MS52（400,2,0）	MS53（500,3,0）	MS54（600,4,0）	MS55（700,5,0）
F6 Maintenance services	MS61（600,1,1）	MS62（800,2,1）	MS63（1000,3,1）	MS64（1200,4,1）	MS65（1400,5,1）
F7 Financial services	MS71（600,1,2）	MS72（800,2,2）	MS73（1000,3,2）	MS74（1200,4,2）	MS75（1400,5,2）

Bicycle manufactures and service providers generate a manufacturing service network, in which service providers provide producer services to the manufactures. According to the service requirements, the manufactures and service providers form MSS through the predator-prey relationships. The specific process is as follows.

(1) The generation of bicycle MSS. The bicycle service enterprise drives the ecosystem evolution of the system.

Assuming a bicycle manufacturer Z2 is driven by the regional service providers F1 - F7 due to their producer services (as shown in Table 1). The manufacturer Z2 does some preliminary study and decides to build a manufacturing service network, and uses the predator-prey model to analysis the network stability, in order to set producer service requirements.

(2) The extension of bicycle MSS. Bicycle service companies provide service information.

Service providers F1 - F7 provide tailored producer services to the manufacturer Z2 through the manufacturing service network. They build a specification table for the producer services, which match the requirement from manufacturer. Meanwhile, they provide the detailed configuration parameters for the bicycle manufacture, in order to increase the probability of being preyed.

(3) The coordination of bicycle MSS. The bicycle manufacturing enterprise has designed the system scheme.

The manufacturer Z2 and the service providers reached a preliminary agreement after negotiation, and further optimized the services quality and prices according to the latest service requirement. At the same time, the manufacturer designed different MSS schemes based on the producer services provided by the service providers. Among the schemes, the Level 1 scheme of MSS solution is that: guidance system - drive system - brake system; Level 2 scheme is: guiding system - drive system - brake system - assist device; Level 3 scheme is: guiding system - drive system - brake system - assist device - personalization; Level 4 scheme is: guiding system - drive system - brake system - assist device - personalization - maintenance services; and Level 5 scheme is: guiding system - drive system - brake system - assist device - personalization - service - financial services.

(4) MSS The development of bicycle MSS. Bicycle manufacturing enterprises on the one hand, preying the service of bicycle service enterprises, on the other hand to optimize the system scheme, the ultimate realization of the ecological evolution of the system.

Firstly, the market adaptation of Level 1 scheme of MSS was tested. Each level scheme chooses suitable producer services for prey based on predation cellular genetic algorithm (Chen et al. 2012). The ecological evolution of MSS is validated step by step. The adaptation level and MSS performance are used to dynamically optimize they MSS.

1) Determine the service attributes. The service genes of the bicycle manufacturer is described as GD = {PR, QU, SE}. PR are the prices of services, QU are the quality of services, SE are the producer services.

2) Determine the services requirement parameters set. Mapping the requirements into the previous service attributes, the requirement parameters set of the bicycle manufacturer is CR = {PR, QU, SE, AD, PC, ME}. Assuming that: PR = 2500 Yuan; QU = 3; SE = 1. AD is the facilitating devices; PC represents the personalization service; ME represents the maintenance services.

3) Calculate the adaptation function. First of all, depending on the type of attribute, the data was standardized into the interval [0, 1], and the adaptation level of producer services is calculated (Chen et al. 2015). (1) The adaptation of price. The price of bicycle is in the range of [500, 3500]. After standardization, the service attribute set and the service requirement set are x1 = 0.1 and y1 = 0.5, respectively. Then using formula (12), the adaptation is Fix (x1, y1) = 0.6. (2) The adaptation of quality. The quality of bicycle is in the range of [1, 5]. After standardization, the service attributes set and requirement parameters set are x2 = 0.5, and y2 = 0.5, respectively. Then using formula (12), the adaptation is Fix (x2, y2) = 1. (3) The adaptation of services. Service type belongs to the state data, because x3 = "no service" and y3 = "service". Then using formula (12), the adaptation is Fix (x3, y3) = 0.

4) According to the manufacturers' understanding of producer services requirements and the composition of bicycle MSS, as well as the relationship between the structural units, the weights of the attributes price, quality and service are 65%, 25% and 65% respectively. Using the formula (13), the Level 1 MSS scheme is Fix (x, y) = 0.64. Using the predation cellular genetic algorithm, the MSS scheme (composed of manufacturer preying service providers on producer services) can be described as MS13 - MS23 - MS33 - Z2. This meets the requirement of evolution but not the requirements of design. The level 2 MSS layer continues to a new generation of ecological evolution.

5) Level 2 MSS layer introduces auxiliary devices based on the Level 1 MSS. The adaptation level is 0.705. Similarly, the predation cellular genetic algorithm was used. However, the MSS scheme MS13 MS23 - MS33 MS43 - Z2 still could not meet the design requirements, and then the Level 3 needs to continue the evolution of MSS; Level 3 MSS introduces the personalized customization based on the Level 2 MSS. The adaptation level is 0.77. Using the predation cellular genetic algorithm, the MSS scheme MS13 - MS23 - MS33 - MS43 MS53 - Z2 still does not meet the design requirements, and the Level 4 continue the evolution of MSS. Level 4 MSS introduces maintenance services based on the Level 3 MSS. The adaptation level is 1. Finally, the producer services attributes completely meet the requirements of manufactures. The predation cellular genetic algorithm was used to form the MSS: MS13 MS23 - MS33 MS43 - MS53 - MS63 - Z2, as shown in Figure 5.

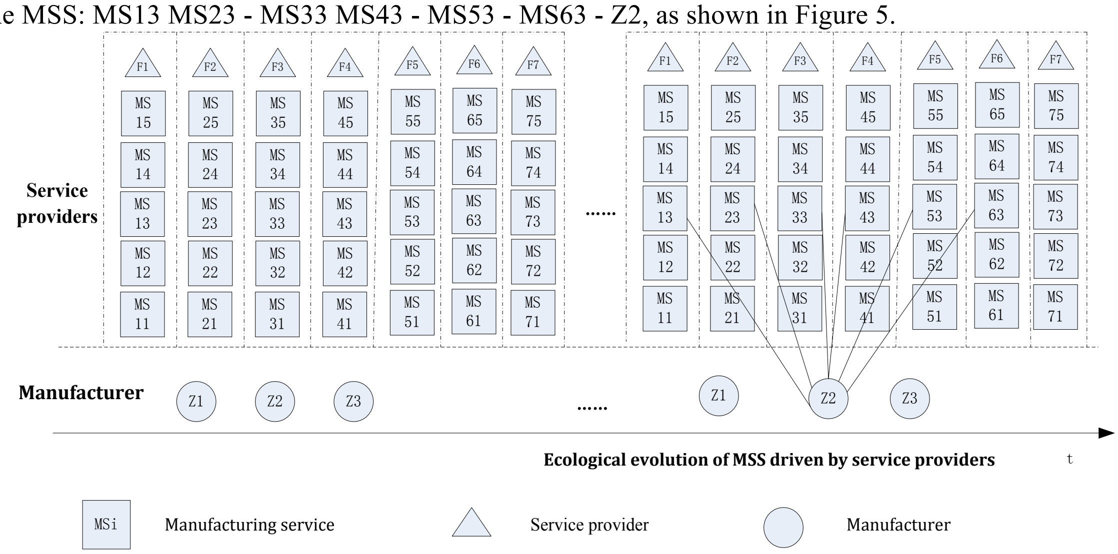

Fig. 5 The example of the ecological evolution of bicycle MSS driven by service providers

(5) The regeneration of bicycle MSS. The bicycle service enterprise has re driven the ecosystem evolution of the system.

If manufacturers request new requirement for bicycle MSS, the system will start and update new functions. Service providers will develop new producer services and reorganizing the producer services to meet the requirement of new producer services. The steps described above can be repeated to generate a new bicycle MSS.

6. Discussion and future research

The research shows that the concept of the manufacturing service in literature is not clear, and this paper provides a definition of manufacturing service and suggests that manufacturing service needs to include both producer service and the servitization of manufacturing. The manufacturing service system need to highlight the relation between the service and the manufacturers, realizing the value creation and allocations of the manufacturing services and sharing the resources of the manufacturing services. The research shows that such manufacturing service system has the following advantages:

(1) The system can support the service enterprises accessible for the market information and service needs promptly, promoting the service enterprises to focus on the development of the manufacturing service; the manufacturing service system also enables the manufacturing enterprises to dispatch the manufacturing service resources promptly and focus on the development of the core products.

(2) The system provides important modes for the operation of the manufacturing service, and the system evolution driven by service enterprises shows broad market prospects and promotes efficient collaboration among service enterprises.

(3) The ecological evolution of the manufacturing service system contains the concept of the business ecological system which will build up dynamic business networks between the service and the manufacturing enterprises, of which the predator-prey mechanism illustrates the essence of the evolution.

The research also shows that more attention needs to be paid to producer services in management field, as well as to the servitization in manufacturing field. The novelty of this paper is to use service enterprises, manufacturing enterprises and end users to distinguish the relations of the manufacturing service. This paper provides a foundation to the future studies on manufacturing service, such as the evolutionary mechanisms of the manufacturing service system between manufacturing enterprises and end users, and the big data analysis application in the ecological evolution of the manufacturing service system.

The manufacturing service system driven by service provider is important to the operations in the company (the service provider). On the one hand, the service provider needs to keep providing innovative services to meet the changing needs of the manufacturers, and this will be the core competitive advantage of the service provider. On the other hand, new management problems will emerge during the course of the evolution of MSS, which requires the collaboration between multiple companies. Several industrial policies, such as Industry 4.0 and Made in China 2025, have been published in recent years. The research and implementation on producer services is regarded as one of the key dimensions in Made in China 2025, and has gained support from Chinese government. Therefore, it is important to study the MSS driven by service providers, which is a key research topic in the field of producer services. This will assist and provide guidance on the establishment and the implementation of policies on manufacturing and services.

The authors will further study how to transform the established evolutionary models into manufacturing service platforms, and how to apply the established evolutionary models to the enterprises. The future research includes the following aspects:

(1) Using big data technologies to collect and analyze the needs of producer services, manufacturers and end users, which could provide customized solutions for MSS and a more comprehensive algorism and optimization for the ecological evolution of the MSS.

(2) Studying the ecological evolution of the MSS mechanism from the perspectives of end users and manufacturers, in addition to the service providers studied in this paper. The ecological evolution of MSS driven by end users is more focused on the analysis of the needs of the end users, while manufacturers is more on the production systems.

(3) Using different key parameters required by different research purposes. The evolution process of MSS requires parameters such as evolutionary cycle, cost, the evolutionary rules, the start condition and the end of the

evolution; while the MSS evolution algorithm requires parameters such as variables, objective function, the evolutionary dynamic mechanism, constraint conditions, and the evolutionary time control etc.

7. Conclusion and implications

In this paper, we established a predator-prey model for the ecological evolution mechanism of manufacturing service systems (MSS) driven by service providers. This mechanism adopts the theory of ecology to simulate the evolution process of MSS in a business ecosystem. In order to understand the evolution, each part of MSS, i.e., manufacturers, service providers and end users, and their relationship need to be studied. This paper mainly discussed the perspectives from the service providers and manufacturers. We developed a predation cellular genetic algorithm to optimize the ecological evolution of MSS. This paper has three main contributions. First, the proposed predator-prey models of MSS can reveal the relations of the manufacturing service selection between service enterprises and manufacturing enterprises. Second, the cellular genetic algorithm based on predator-prey mechanisms can better simulate the internal evolutionary mechanisms of the manufacturing service system. Third, the results can be widely used in the construction of the manufacturing service platforms between service enterprises and manufacturing enterprises.

A limitation of the current study is that it remains to provide a quantitative account of division of monetary value between service provides and manufacturers. This article does not apply the latest information technology, such as cloud computing, Internet of things, big data, etc.

The future research includes the MSS evolution mechanism in a broader context, and using big data technology to support the decision-makings in the MSS evolution process. This paper has studied the mechanisms of the ecological evolution of the manufacturing service system (MEEMSS) between service and manufacturing enterprises driven by the service enterprises. Further research is needed to study the MEEMSS between manufacturing enterprisers and end-users driven by end-users and the MEEMSS among end users, manufacturing and service enterprises, driven by manufacturing enterprises. These three MEMSSSs will completely resolve the issues on the ecological evolution of the manufacturing service system as well as promote the integration of manufacturing and services, achieving the transformation of the servitization in the manufacturing industry.

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