This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TSC.2020.3016660, IEEE Transactions on Services Computing

Value Entropy: A Systematic Evaluation Model of Service Ecosystem Evolution

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***Abstract*—With the development of cloud computing, service computing, IoT(Internet of Things) and mobile Internet, the diversity and sociality of services are increasingly apparent. With the increasing complexity of collaborative relationships between services, service ecosystems are beginning to emerge with the characteristics of natural ecosystems, economic systems and complex networks. Under this context, how to realize systematic evaluation of service ecosystem is of great significance to promote its sound development. Based on this, this paper proposes a value entropy model that links the operating state of the system with the efficiency of value creation, which helps to clarify the performance of the service ecosystem from the perspective of multi-dimensional integration. In addition, a computational experiment system is established to verify the effectiveness of value entropy model, which stimulates the competitive evolution process of two service ecosystems with different strategies. The result shows that our model can provide new ideas for the analysis of service ecosystem evolution, and can also provide decision support for the optimization of operation strategy.**

***Index Terms*—Service ecosystem, Value entropy model, Systematic evaluation, Computational experiment.**

I. INTRODUCTION

With the development of information technologies such as service science [1], cloud computing [2], Edge computing [3] and mobile Internet, more and more enterprises and organizations encapsulate their business capabilities (e.g., resource, platform, software, business and data) into services (e.g., Web service, RESTFul service, OpenAPI and Mobile APP). Further, these services can meet customers' diverse needs through dynamic composition and convergence (e.g. Workflow, Composition/Mashup and Personalized Service). In the long-term competition and cooperation, a complicated interactive relationship among service nodes can be formed through their self-organization mechanism. With the rapid development of service economy[4] and software service technologies[5], service ecosystems begin to emerge with the characteristics of natural ecosystems, economic systems and complex networks [6-9].

There are three main roles in service ecosystem, namely service providers, service consumers, and service operators. Service providers refer to those who are in possession of resources, and provide services to service consumers within a specific time. Service consumers refer to those who consume the resources. Service operators can realize and adjust the supply and demand matching between service providers and service consumers, thus to increase the efficiency of value creation. The current market competition is rapidly changing and user needs are increasingly individualized. Service ecosystem needs to evolve to adapt to these changes through reforming and transforming their collaboration relationship [10,11].

Alibaba's e-commerce platform is a very typical service ecosystem. Its goal is to serve as a bridge between merchants and users, which is used to solve the problem of information asymmetry between the two parties. In order to achieve this goal, the services of the service ecosystem are divided into three levels: ① The primary service circle is the basis for the further propagation and evolution of service ecosystem. This circle gives birth to tools (e.g. cloud computing service, storage services, security service), use optimizations (e.g. intelligent algorithms services), and workable instantiations of data models (e.g. data mart). ② The secondary service circle is about utilizing base technology for developing consumer-oriented e-commerce platforms, e.g. Taobao, Tianmao, Xianyu, etc,. This circle can provide a lot of basic business services, including finantial service, logistics service, order processing service, etc,. ③ The tertiary service circle is formed around the secondary service circle. It mainly refers to additional services provided by third parties through the platform interface, such as data analysis service, promotion service, etc,.

Up to this day, service ecosystem has become an important factor in the fierce global market competition. To maintain the competitiveness of a service ecosystem, we needs to analyze and predict the system evolution path. As a result, how to effectively evaluate the overall performance of the service ecosystem has become critical. Service ecosystem is a complex social-technology system with the characteristics of natural ecosystems, economic systems and complex networks. However, the traditional Quality of Service [12] and System Performance Evaluation [13] can only focus on one aspect of system performance, which are insufficient in the measurement of evolution status of service ecosystem. We need a multi-dimensional integrated model that can systematically analyze and evaluate the service ecosystem.

In service ecosystem, each service node is social and autonomous, which increases the diversity, uncertainty and dynamics of service provision. With the increasing complexity of interactive relations, the failure of a single service node may

Thanks for the support provided by National Key Research and Development Program of China (No. 2017YFB1401200), National Natural Science Foundation of China (No.61972276, No. 61832014, No. 41701133). (Corresponding author: Shufang Wang)

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give rise to cascade effect of the service network, and even causes unpredictable emergencies of the whole system. The orderliness of service nodes directly determines the efficiency of value creation. In the field of thermodynamic, entropy is used to describe the chaos degree of a system. In the field of information, Shannon uses information entropy to describe the uncertainty of information sources. In the field of ecology, Shannon-Weiner index based on entropy theory is used to measure population diversity[14]. Inspired by these ideas, we have proposed the value entropy model to measure the orderliness of service ecosystem and then evaluate the efficiency of the whole ecosystem in value creation and production.

The rest parts of this paper are organizaed as follows. Section II introduces relevant work of service ecosystem; Section III proposes the value entropy model, including entropy measurement, value analysis and operation strategy; Section IV designs the computational experiment system from the perspective of value creation in service ecosystem; Section V verifies the applicability of the value entropy model with experiment simulation; Section VI discusses the effectiveness of value entropy model in practical cases; Section VII concludes the paper.

II. Background and Motivation

The concept of service ecosystem is originated from the ecosystem theory in ecology. This section mainly gives the origin and current research status of the service ecosystem, so as to make clear the motivation of our research.

A. Origin and classification of service ecosystem

Moore firstly applied the ecosystem thought in the business field and thereby proposed the concept of business ecosystem[15]. He pointed out that business ecosystem is an economic symbiotic union based on organizational interaction, and a multi-level system structure composed of stakeholders across industry boundaries. After that, Vargo and Lusch proposed service-dominant logic to replace traditional commodity-dominant logic, which defined the service ecosystem as a socio-technical system featured by complexity, self-evolution and autonomy [16]. In recent years, the service ecosystem theory is also concerned by industrial circle. Both traditional industries and emerging industries are devoted to constructing the service ecosystem to remain their competitive advantages.The typical cases are shown below.

(1) Software & service ecosystem

In the long-term operation of an enterprise, the software system needs to be continuously restructured to support the continuous changes of the business, such as the emergence of new services, the demise of old services, the update of the composition relationship between services, and so on. In the end, all kinds of software services from different providers form a complex functional network, that is, a software service ecosystem[17].

(2) Cloud manufacturing service ecosystem

In order to adapt the network manufacturing trends in the future, more and more enterprises encapsulate their respective distributed resources into the Web service to shares diverse and distributed manufacturing resources. These services can cover the whole product development life cycle by means of dynamic composition, that is cloud manufacturing service ecosystem[18].

(3) O2O life service ecosystem

Online to Offline (O2O) life service is a kind of commercial element integration mode, which relies on online ecological engine to drive offline life services by utilizing the mobile internet technology [19]. After these daily life service resources (such as food, clothing, housing, entertainment, entertainment, etc.) are redesigned and reorganized to form a closed loop of user consumption, the O2O life service ecosystem can maintain a long-term competitive advantage.

B. Research topics of service ecosystem

The analysis of the service ecosystem has always been the focus of academic circles, and its research is mainly divided into three parts:

(1) Evaluation

To evaluate service ecosystem, some researches propose the scale, availability, utilization and other performance indexes by using the statistical analysis method[20]. Zheng et al. collected 21,197 public services from the Internet and analyzed their round-trip time (RTT) and failure-rate (FT) under real Internet environment [21,22]. Cavallo et al. collected RTT of services at different time points to constitute the time sequence of QoS, and then applied the autoregressive moving average model (ARMA) to predict such time sequence [23]. Godse et al. further gave the predication of four QoS indexes (RTT, throughput, accessibility and availability), and obtained QoS evaluation by weighting the predicated value [24]. Zhang et al. took into account the social and economic properties of service ecosystem and proposed the people-service-workflow network (PSWN) model [25]. Wu Wenjun and Li Wei et al. investigated the evaluation methods of group software, and analyzed TopCoder and AppStore [26].

(2) Analysis

Sawatani et al. believed that the service ecosystem combined the self-organizing characteristics of complex system and the coevolution characteristics of ecological system [27]. In order to improve the undersatanding of service ecosystem, Alistair Barros et al. defined five key roles in Web service ecosystem, thus to discuss service provision, service discovery and choreography, service quality management, service coordination and other key problems[8]. Moore pointed out that enterprises play different roles in service ecosystem and occupy different ecological niches depending on their own resources and abilities [15]. Villalba et al. designed the multi-agent-based simulation model to analyze the features of service ecosystem, including self-organization, self-adaptability and continuous evolvability, etc[28,29]. Mostafa et al. modeled each service into the independent Service Agent and defined the service composition process as the self-organization collaboration among service agents [30].

(3) Intervention

In fact, the status of service ecosystem will directly decide the quality of service provision. Hence, it is very important to guide and optimize the evolutionary process of service ecosystem. Some researches used the reinforcement learning method to deal with the dynamics and uncertainty of the internet environment and obtain the optimized service composition [31-34]. Part of study changed the optimization problem of service network into the graph search problem, and the shortest path method is utilized to obtain the optimal solution in the service network [35, 36]. Some researchers proposed applying the control theory to the management of service ecosystem by monitoring its service status [37,38].

From the above research status, it can be seen that the evaluation of the service ecosystem is at the first stage of its research, which is the basis of the other two stages. However, current research still lacks a multi-dimensional systematic evaluation model of service ecosystem. It is difficult for existing methods to reveal the evolution status of service ecosystem. In order to face this challenge, this paper proposes a value entropy model of service ecosystem from the perspective of value network, including entropy measurement, value analysis and operation strategy, so as to provide a new technical means for the evaluation and analysis of service ecosystem.

III. The Value Entropy Model of Service Ecosystem

The service ecosystem is a highly dynamic value generation system, in which the niche of each service node is formed in the process of long-term competition and cooperation. This section proposes the value entropy model of service ecosystem from the prospective of supply and demand matching.

A. Entropy measurement of service ecosystem

In service ecosystem, service nodes at different ecological niches (represented by different colored circles) have different service capabilities and service attributes. They can work together to jointly create value for customers .As shown in Fig.1, the value creation of service ecosystem consists of three elements: Input, Output, and Operation. Input means customers' value demands, which drives the constant evolution of service ecosystem. Output means the value created by the service ecosystem in a certain period of time. Operation means the value creation ability of service ecosystem. Because the concept of value is rather vague, it is difficult to connect the current state of the service ecosystem with its value creation capabilities.

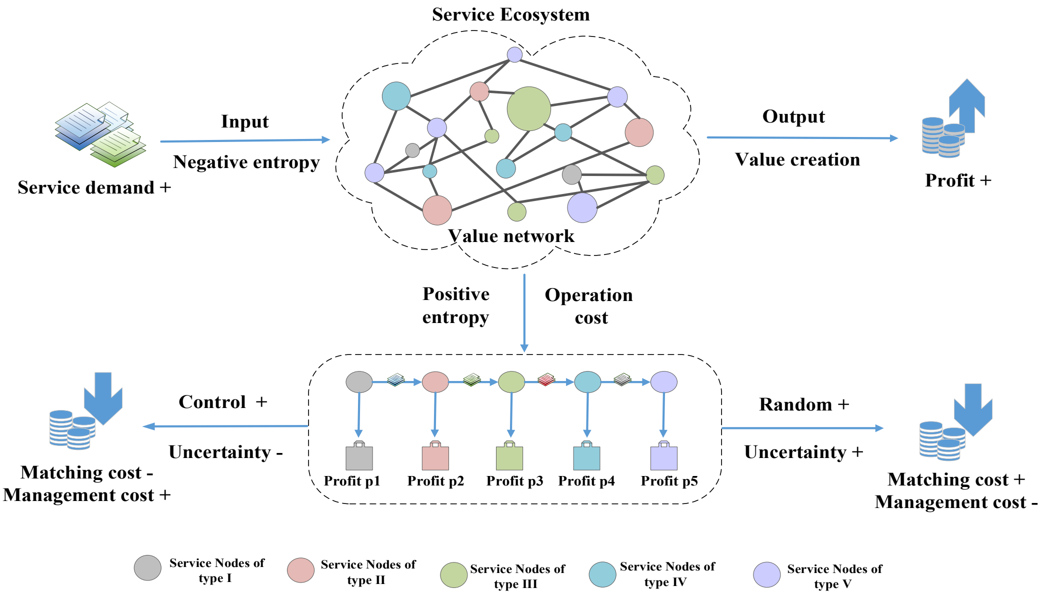

Fig.1 The relationship between service ecosystem and entropy

The value creation process of service ecosystem consists of two steps: node management and node matching. The node management first classifies the service nodes into different niches, then sorts all nodes in the niche. As a result, the nodes in the same niche form an ordered sequence and the niches are still in an unordered state. The goal of node matching is to find service nodes as quickly as possible for demands, which needs to first find a suitable niche, and then find the suitable node in the niche. When the orderliness of the entire service ecosystem is higher, the faster the speed of finding suitable nodes, the higher the efficiency of value generation. However, maintaining the order of the ecosystem requires costs, including management costs (maintaining the order of service nodes) and matching costs (finding suitable service nodes).

Inspired by the application of Entropy concept in information theory, ecology, etc., we proposes the value entropy model to measure the orderliness of service ecosystem, and then to evaluate its value generation efficiency. In order to maintain the continuous operation of ecosystem, it is necessary to continuously input the demands (negative entropy), and generate value through the value network (generate positive entropy). If the negative entropy input is less than the positive entropy generated, the entropy value of the system will increase, leading to an increase in the uncertainty of supply and demand matching. Otherwise, the entropy value of the system decreases, resulting in a reduction in the uncertainty of supply and demand matching. Based on the traditional definition of entropy, the entropy of service ecosystem can be defined as:

$$H_i = -\sum_{j=1}^{n} p_j \log_2 p_j$$
$$\text{Constraints:} \quad p_j = \frac{N_j}{N_{total}}, \text{ and } \sum_{j=1}^{n} p_j = 1 \qquad (1)$$

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In which, p_j represents the distribution probability of service nodes of the *i-th* type, N_j is the number of service nodes of the *j-th* category, and N_{total} is the total number of service nodes in system. In the actual application of Entropy Model, the niche division criteria of service nodes are mainly based on their value creation efficiency. The value creation efficiency of a node can be defined as:

$$E_r = \frac{g_r}{c_r} \quad (2)$$

in which g_r is the amount of value created by node r within a certain period, and c_r is amount of value consumed by node r within a certain period of time.

Based on formula (1) and its constraint condition, Lagrange Multiplier Method is adopted to construct formula (3):

$$L(p,\lambda) = -\sum_{j=1}^{n} p_j \log_2 p_j - \lambda(\sum_{j=1}^{n} p_j - 1) \quad (3)$$

The derivative of formula (3) can be obtainedas follows:

$$\frac{\partial L(p,\lambda)}{\partial p} = -\log_2 p_j - \frac{1}{\ln 2} - \lambda = 0$$

$$\Rightarrow \ p_j = 2^{-\lambda - \frac{1}{\ln 2}}, \ j = 1, 2, \cdots, n$$

The constraint condition of formula (1) is used to calculate the probability when obtaining the maximum entropy:

$$\sum_{j=1}^{n} p_j = n 2^{-\lambda - \frac{1}{\ln 2}} = 1$$

$$\Rightarrow \ 2^{-\lambda - \frac{1}{\ln 2}} = \frac{1}{n}$$

$$\Rightarrow \ p_1 = p_2 = p_3 = \cdots p_n = \frac{1}{n}$$

Then the maximum entropy value is calculated as:

$$H_{max} = -p_1 \log_2 p_1 - p_2 \log_2 p_2 - \cdots - p_n \log_2 p_n = \log_2 n \quad (4)$$

Because its derivation $H_{max}' = \frac{1}{n \ln 2} > 0$, H_{max} is the monotone increasing function, in which n is the number of categories of service node. It indicates the stronger the ecological diversity is, the bigger the entropy value is and the more disordered the ecosystem is. The scale of service ecosystem can decide the upper limit of ecological diversity, thus influencing the changes in entropy.

B. Value Analysis of service ecosystem

The external demand input cannot be controlled, but the order within the service ecosystem can be changed. Different service operation strategies directly affect the value generation efficiency of the service ecosystem.As shown in Fig.2, three different operating modes are presented: Fully Controlled Mode (all niche and nodes are arranged in order), Fully Random Mode (all the niche and nodes are disorderly) and Partially Controlled Mode (the niche is ordered, but the nodes within the niche are disordered). The circles represent service nodes in the ecosystem, and the numbers represent the value creation efficiency of the node. The nodes in each dashed box are in the same niche.

Here, management cost is expressed as the product of node management time complexity and system unit time cost, and matching cost is expressed as the product of node matching time complexity and system unit time cost. According to the commonly used sorting and seearching algorithms, node management time complexity and node matching time complexity can be set as O ($n \log_2 n$) and O (n), respectively.

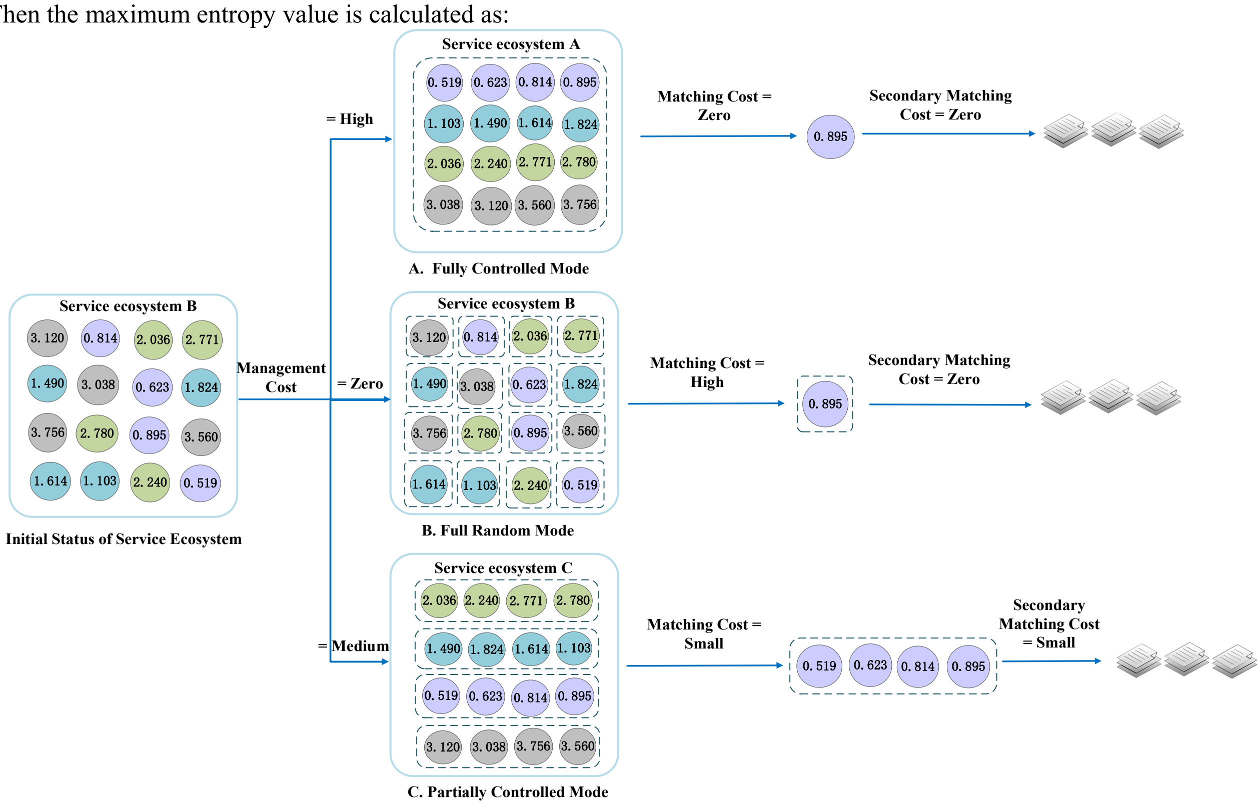

Fig.2 Cost Comparison of three operation strategies of service ecosystem

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Considering the scale of service ecosystem, management cost and matching cost can be expressed as follows:

$$c_1 = k \cdot \frac{N}{m} \log_2 \frac{N}{m} \tag{5}$$

$$c_2 = k \cdot m \log_2 m \tag{6}$$

Where k (k> 0) is the cost coefficient per unit time of the system, N is the system size, and m is the number of niches, that is, the number of node classifications. Therefore, the operating cost (c) and actual value benefit (v) of service ecosystem can be expressed as:

$$c = c_1 + c_2 = k \cdot \left(\frac{N}{m} \log_2 \frac{N}{m} + m \log_2 m \right) \tag{7}$$

$$v = \sum_{j=1}^{n} g_j - c \tag{8}$$

According to the derivation of formula(7), we can get the extreme points of costand and then derive the extreme point of value benefit.:

$$c' = k\left(\log_2 m - \frac{N}{m^2} \log_2 \frac{N}{m} + \frac{1}{\ln 2} - \frac{N}{m^2} \frac{1}{\ln 2} \right) = 0$$

$$\Rightarrow m_l = \sqrt{N} \qquad \text{//the extreme point}$$

$$\Rightarrow c_{1-\min} = c_{2\text{-}\min} = k \cdot \sqrt{N} \log_2 \sqrt{N}$$

$$\Rightarrow c_{\min} = 2k \cdot \sqrt{N} \log_2 \sqrt{N}$$

$$\Rightarrow v_{\max} = \sum_{j=1}^{n} g_j - c_{\min} = \sum_{j=1}^{n} g_j - 2k \cdot \sqrt{N} \log_2 \sqrt{N}$$

The running cost takes the minimum value at the extreme point (m_l). On the left side of the extreme point, the cost (c)monotonically decreases; on the right side of the extreme point, the cost (c) monotonically increases. In contrast, the value benefit (v) takes the maximum value at the extreme point.

The relationship between ecological diversity and actual value benefit is shown in Fig.4. It can be known that too high or too low entropy value is not conducive to the value creation of service ecosystem. When the ecosystem reaches the optimal entropy value, the management cost and matching cost reach the equilibrium point, the operation cost is the lowest, and the actual value benefit is the largest. The optimal value entropy can be expressed as follows:

$$H_b = \log_2 m_l = \log_2 \sqrt{N} \tag{9}$$

Here, we take the three service ecosystems in Fig.3 as examples to illustrate the nonlinear relationship between entropy and value benefit.

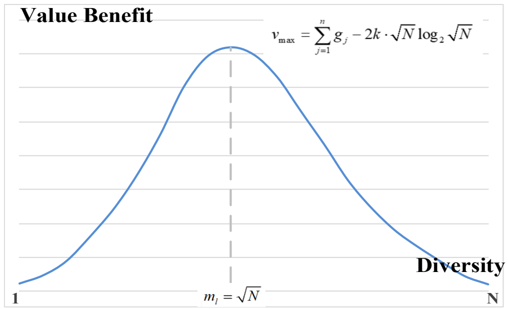

Fig.3 The relationship between ecological diversity and actual value gain

TABLE.1
THE COMPARISON OF SYSTEM INDICATIONS OF THREE CASES IN FIG.2

Market Env / Opeartion Mode	Demand sequence	Single niche	Entropy	Cost	Value benefit
Service ecosystem A (fully controlled mode)	the value is V	A single niche (only one node type)	$H_A = \log_2 1 = 0$	management cost >> matching cost $c_A = k(16\log_2 16 + 1\log_2 1) = 64k$	$v_A = V - c_A = V - 64k$
Service ecosystem B (fully random mode)	the value is V	Each node is in an independent niche (N node types)	$H_B = \log_2 16 = 4$	management cost <<matching cost $c_B = k(1\log_2 1 + 16\log_2 16) = 64k$	$v_B = V - c_B = V - 64k$
Service ecosystem C (partially controlled mode)	the value is V	All nodes are divided into m niches, and keeps the order of nodes in each niche. (m node types)	$H_C = \log_2 4 = 2$	management costs and matching costs are more balanced. $c_C = k(4\log_2 4 + 4\log_2 4) = 16k$	$v_C = V - c_C = V - 16k$

Since k> 0, the entropy values and value benefit in the three modes are compared as follows:

$$H_A < H_C < H_B \text{, and } v_C > v_B = v_A$$

Among them, the entropy value of service ecosystem A is the smallest, and its unnecessary management costs are paid for the strict internal control; the entropy value of service ecosystem B is the largest, its internal collaboration is too disordered and the matching cost is high; the entropy value of service ecosystem C is closest to the optimal value entropy, its management cost and matching cost are the most balanced and it has the largest actual value benefit.

C. Operation strategy of service ecosystem

As a supply-demand matching system, the evolution process of service ecosystem is not only affected by the supply-side management mode, but also by the demand-side environment. In practice, there are two kinds of typical demand secnarios: a mature market environment (D_M) and a emerging market environment (D_E). In a mature market environment, the market potential has been fully developed and the number of demands has remained stable for a long time. In the emerging market environment, the market potential has not been fully developed, and the number of demands may show explosive growth.

Based on the previous discussion, it can be seen that the value benefit of partially controlled mode is better the other two modes. As a result, the partially controlled mode is popular in the operation of supply side in sercice ecosystem. In the service ecosystem, if there are more nodes in the control mode, we call this operation mode as the control-dominated strategy, and vice versa as the random-dominated strategy. For different operating stratigies, the decisive elements of their cost composition are different. For the control-dominated strategy, management cost plays a decisive role, which is proportional to the amount of service nodes; while for the random-dominated strategy,

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matching cost plays a decisive role, which is proportional to the amount of demands. Therefore, the cost of control-dominated strategy (C_a) and random-dominated strategy (C_b) can be expressed as formula 10 and formula 11:

$$c_A = k\frac{N}{m_A}\log_2\frac{N}{m_A} \quad (10)$$

$$c_B = km_B\log_2 m_B * d \quad (11)$$

Where k (k> 0) is the cost coefficient per unit time of the system, N is the number of nodes (i.e. system size), m_a is the number of niches in the control-dominated strategy, and m_b is the number of niches in the random-dominated strategy, d is the amount of demands in the market environment.

TABLE.2
THE COST OF TWO OPERATION MODES IN DIFFERENT MARKET ENVIRONMENTS

Market Env / Opeartion Mode	Stable Demand Sequence	Explosive Demand Sequence
Control dominated strategy	C_a (large)	C_a (small)
Random dominated strategy	C_b (small)	C_b (large)

Based on the above conclusions, Table 2 shows the cost representation of different operating strategies in different market environments.

(1) In a mature market environment, the system still maintains a considerable scale, but the number of needs to be processed is not large. Based on formula (10) and (11), the cost of the control-dominated strategy (C_a) is fixed and proportional to system size; the cost of the random-dominated strategy (C_b) remains low. As a result, the cost of the control-dominated strategy is larger than that of the random-dominated strategy ($C_a > C_b$). So, in a mature market environment, a random-dominated strategy with strong ecological diversity has an advantag, that is, the larger the entropy value, the higher the value benefit.

(2) In a emerging market environment, the system still maintains a considerable scale, but the number of demands to be processed has grown dramatically. Based on formula (10) and (11), the cost of the control-dominated strategy (C_a) is fixed; the cost of the random-dominated strategy (C_b) continues to increase sharply as the matching frequency increases. As a result, the cost of the control-dominated strategy is smaller than that of the random-dominated strategy ($C_a < C_b$). So, in a emerging market environment, a control-dominated strategy with weak ecological diversity has an advantage, that is, the lower the entropy value, the higher the value benefit.

Further, we can find the dividing point of the quantity of demand (d), so as to make a quantitative distinction between the two market environments. The derivation process is as follows:

$$k\frac{N}{m_A}\log_2\frac{N}{m_A} = km_B\log_2 m_B * d$$
$$\Rightarrow \ d' = \frac{N*(\ln N - \ln m_A)}{m_A * m_B * \ln m_B} \quad (12)$$

As shown in Fig.4, when $d < d'$, the cost of control-dominated strategy is higher ($C_a > C_b$) and its value benefit is lower; when $d > d'$, the cost of random-dominated strategy is higher($C_b > C_a$) and its value benefit is lower.

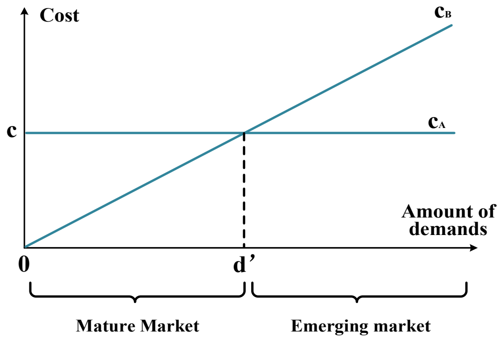

Fig.4 Relationship between model mode and market environment

According to formula (12), when the scale of service ecosystem is expanded, *d'* will move to the right, and the range in which the random mode is dominant will become larger; when the scale of the service ecosystem is reduced, *d'* will move to the left, and the scope of the control mode is dominant will become larger. The above analysis results provide basis for studying the optimized operation strategy of service ecosystem. We can draw the following related conclusions based on the value entropy model:

(1) For a given market environment, there is an optimal entropy value that maximizes the value benefit of the service ecosystem. Too high or low entropy is not conducive to the creation of actual system value benefit.

(2) Under the condition of mature market environment, the random-dominated strategy with higher entropy value has more advantages and higher returns.

(3) Under the condition of emerginge market environment, the control-dominated strategy with lower entropy value has more advantages and higher returns.

IV. DESIGN OF COMPUTATIONAL EXPERIMENT SYSTEM

In order to verify the applicability of the value entropy model, the corresponding computational experiment system is constructed as the artificial society laboratory. Borrowing the idea of service bridge [39], the evolution of service ecosystem can be abstracted as a continuous matching process between the supply side and demand side. Based on the concept, related design details are divided into three parts: design of supply side, design of demand side, and design of system operation.

A. Design of Supply-side

The agent is an entity with characteristics of autonomy, society, reaction, and pre-action. Service nodes in the service ecosystem have similar characteristics, such as interconnection rather than isolation, autonomy rather than obedience, etc. Therefore, the agent becomes a natural metaphor for the active entities of the ecosystem. In the computational experiment system, the supply-side agent stands for the service nodes offering goods or services. They are active and dynamic, serving as the active behavior entity in system environment.

All supply-side agents search their own specific orders (e.g. primary node ->primary order, secondary node->secondary order, and third-level node ->third-level order) in the environment and consume certain capital in the searching process. After acquiring orders, their own capital will increase

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accordingly and produce secondary orders for downstream nodes. When their capital reaches the reproduction threshold, genetic evolution is conducted to produce new child agents of the same kind. When their capital is smaller than their death threshold, they die and disappear.

The survival of the fittest among service nodes are key factors driving the evolution of service ecosystem. In the intense competition among service nodes, those nodes that are not competitive are likely to be eliminated. In order to survive in the ecosystem, service nodes must improve their decision-making and behavioral skills through a variety of learning methods. The evolution process of individual node is the result of the combined effects of individual learning, organizational learning and social learning.

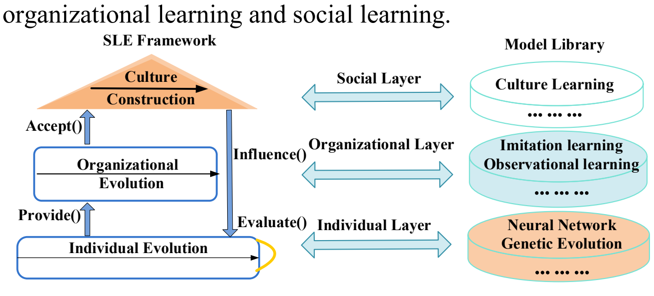

Fig.5 SLE Modeling Framework

Based on the work in [40], the SLE framework is used to describe the characteristics of the supply side agents. As shown in Fig.5, the SLE framework is composed of two parts: the left column indicates three modeling layers and the right column indicates the implement models adopted by each layer. There is a feedback loop among the three modeling layers: the modeling of individual evolution is at the bottom layer, which simulates the genetic evolution phenomenon of individual node in service ecosystem; the modeling of organizational evolution is at the intermediary layer, which simulates the imitation and observational learning among service communities; the modeling of social evolution is at the top layer where the knowledge of some elites can be extracted as culture, which simulates the accelerated evolution of the whole ecosystem promoted by culture.

The SLE is a customizable modeling framework. Depending on the specific needs, the models and techniques required for each layer can be selected and adopted from the corresponding model library. Model elements in the model library can be added, deleted, and modified as needed. The implementation details of each layer are shown as follows:

- **Individual evolution layer**: The bottom layer is the micro level, which is used to simulate the independent evolution of individual service nodes in the real world. According to the rule of survival of the fittest, each individual node needs to continuously improve its own ability in order to survive in the fierce market competition. The evolutionary models commonly used here include genetic algorithms, reinforcement learning, neural networks, and so on.
- **Organizational evolution layer**: The middle layer is the organizational level, which is mainly used to simulate the cooperation between service nodes to enhance the competitiveness. In the real world, market competition has evolved from the competition between single nodes to the competition between groups. The evolutionary models commonly used here include observational learning, imitation learning, and so on. Different evolution mechanisms can lead to different outcomes.
- **Social evolution layer**: The top layer is the cultural level, which is mainly used to simulate the impact of elite culture on individual evolution in society. In the real world, some elites with excellent knowledge will gradually emerge from the group because of their excellent performance. Then, their knowledge can be extracted into culture, and it can affect the individual evolution at the micro level. For example, the operation mode of service ecosystem (random mode or control mode) can accelerate or hinder the development of many single nodes in different scenarios.

B. Design of Demand Side

In experiment system, the demand-side elements (i.e. order) form the system environment module together, which is regarded as a container for all supply-side agents. The position of each order is fixed in its entire lifecycle. If one order is processed by some agents or its lifecycle is over, it will disappear. After some fixed time cycles, new orders will emerge according to the designed order generation model, including order amount, order category (e.g. primary-level order, second-level order, third-level order), order distribution, profit value of order unit, etc. Thus, all kinds of market fluctuation trend can be simulated, such as mature market environment and emerging market environment.

In experiment system, each order has a certain complexity, that is, the order needs to go through several links to be processed. Fig.6 shows the virtual "food chain" including three types of service nodes. Primary orders are the source of value benefit for all nodes, which requires three steps to complete. At first, the primary order is disposed by first-level service node and generates the secondary order, and then the secondary order will be handled by secondary node to produce the third-level order. Until the third-level order is processed by third-level nodes, all the service nodes in the relevant links can obtain the corresponding share of profits. If the third-level order is not disposed by specific service nodes within the period, early profits generated by the primary order will also be invalid.

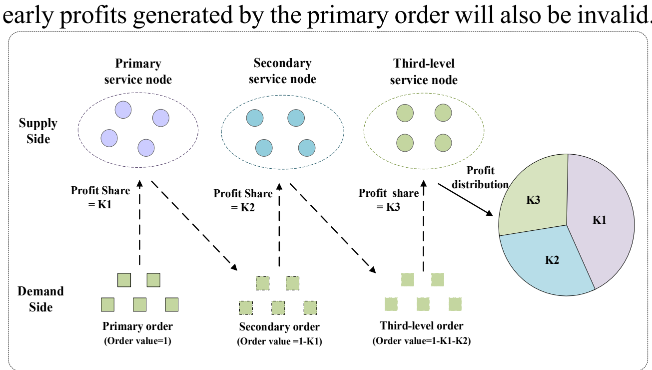

Fig.6 The "Food-chain" Relation in Service Ecosystem

Here, the demand-side characteristics of a particular domain can be descripted by Formula (13):

$$Demand\_Char =< Trends, Volume, Location, Category, QoS\ Preference > \quad (13)$$

Based on our existing domain knowledge, the content of each element can be described as follows:

- ***Trends.*** It represents the macro market characteristics of the analyzed domain. In real world, the fluctuation of market trends conforms to a certain rule. According to the magnitude of fluctuation, the trends can be categorized as stable market trends and fluctuated market trends.
- ***Volume.*** It represents the potential market size of the domain analyzed. In actual environment, the market size varies a lot among domains, which is determined by the user's purchase frequency and product unit price. For example, E-commerce service belongs to high-frequency & high price domain, which has a large potential market size.
- ***Location.*** It represents the geographical location of the domain analyzed. Because of differences in economic development levels, customer consumption habits, etc., the market characteristics vary greatly among regions, which may be reflected in the number of orders, type of orders, unit price of orders, etc.
- ***Category.*** It represents the diversity of the service demands. Different demands need to be met by different service providers. Even for the same product or service, service providers may vary a lot in price and quality.
- ***Complexity***: It represents the number of links an order needs to be processed. Generally speaking, the complex orders need to be processed by different service chain links in turn. If the initial complexity of an order is 3, the value network needs to complete such order through the cooperative process between three service links.
- ***QoS (Quality of Service) Preference***. It represents the dynamics of user preferences. In the real world, not only the total number of customer demands may change, but the preferences of individual demand may also change. For example, with the development of social economy, customers' consumption will be upgraded, from price preference to quality preference. This change will lead to a reduction in the size of the original market and an increase in the share of emerging markets

C. Design of System operation

The evolution direction of service ecosystem is determined by the matching process between the supply-side and the demand-side. As shown in Fig.7, a variety of experiment scenarios can be customized by setting and combing the supply-side and demand-side parameters. Without external intervention, experimental systems can be used to simulate the natural evolution of service ecosystem. The evolution result depends mainly on initial conditions and internal mechanisms. If there is external intervention, the experimental system is mainly used to simulate the controlled evolution to assess the effectiveness of the intervention. By observing the evolution phenomena of ecosystem in experiment system, it is possible to intuitively find the appropriate intervention strategies.

In order to make the experiment easy for readers to understand, the prototype of the experiment is based on the Alibaba and Tencent. In practice, they use different strategies to build their own ecosystem, and compete fiercely with each other in certain areas. In the operation scene of our experiment system, the service ecosystem α (red symbols) adopts a control-dominated strategy (similar to Alibaba), and the service ecosystem β (blue symbols) adopts a random-dominated strategy(similar to Tencent). The entire scene is divided into 5 regions: initial area (1 and 4), adjacent area (2 and 5), and emerging area (3). They represent the core business, related business, and emerging business of a service ecosystem respectively. Green area represents the order-rich regions, and the depth of the green reflects the intensity of orders.

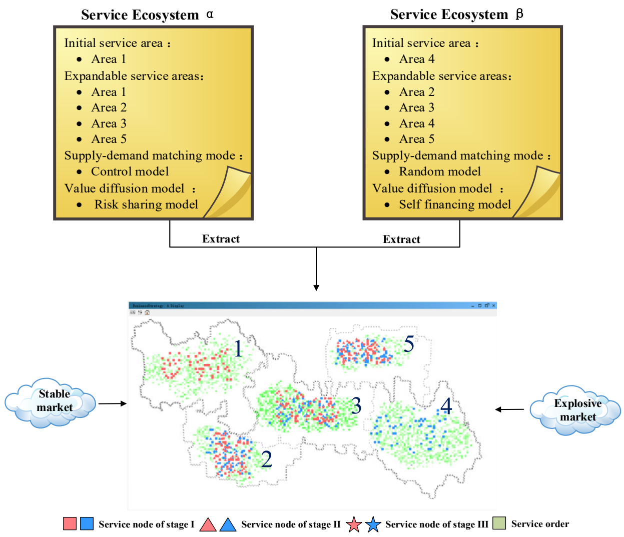

Fig.7 The design of computational experiment system

In the initial state of the experiment, the agents of two ecosystems are respectively distributed in their core business areas: service ecosystem α is in area 1 (similar to Alibaba's e-commerce), and service ecosystem β is in area 4 (similar to Tencent's social media). As the scale of the service ecosystem expands, their agents will gradually enter neighboring areas and emerging areas. The active areas of the two ecosystems will overlap each other. During this period, three types of agents (primary node, secondary node, and third-level node) will be produced, which are represented by different symbols with different shapes (square, triangle, star). The farther the agent is from its core area, the higher the cost it consumes per unit time. When agents belonging to different ecosystems meet, the one with large capital value can kill the other and possess its value. As more and more agents from different ecosystems enter the same area, the competition between them will become more intense.

In the computational experiment environment, various operation mechanisms of service ecosystem can be evaluated, including some pressure test and boundary test. The purpose of the service operation strategy is to adjust the relationship between different nodes. The performance of different service strategies varies widely. Here, we take two kinds of operation strategies as the experiment objects. The related details are given as follows.

Option 1: Control-dominated strategy

The control-dominated strategy will use the virtual hub to coordinate the management of all nodes, corresponding to the strong relationship of the value network. The type of service ecosystem has a strong ability to share risks. After a fixed

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period, the virtual hub will collect the profits of all nodes and then distribute them to all nodes according to certain rules. In this way, a single node has stronger survivability, and it is easier to go farther from the core area.

Option 2: Random-dominated strategy

The random-dominated strategy emphasizes the autonomy of service nodes and the equal cooperation between nodes, which corresponds to the weak relationship of the value network. In the process of value creation, each service node is responsible for its own profits and losses, and there is no risk sharing mechanism. The survival of the fittest among the nodes leads to a stronger adaptability of the entire system. In this way, the viability of a single node is not strong, and it will not easily deviate from the core area.

V. Experiment Evaluation of Service Ecosystem

In this section, various experiment scenarios are designed to compare the performance of two service ecosystems that adopt different operating strategies. The experimental results will be used to verify the validity of the entropy model.

A. Initialization of Computational Experiment

(1) Experimental scene

Case 1, the overall market demand remains relatively stable only with periodic and small range fluctuation; case 2, the market demand in the emerging area explodes in the 280th cycle.

(2) Experimental subject

The experiment set up a competitive game between service ecosystem α and β within the same environment. Service ecosystem α and β adopt control-dominated strategy and the random-dominated strategy respectively.

(3) Parameter setting

In the construction of the "New Retail" business ecosystem, Alibaba and Tencent have adopted control-dominated and random-dominated strategies, respectively. So, they are used as the prototypes of service ecosystem in the experiment. Based on the public operating data of the two companies from 2015 to 2018 [41,42], the experimental parameters are set as follows:

TABLE 3
Parameters Setting of Computational Experiment

System Variable	Experiment Setting
Environment Setting	
Number of environment areas	5
Agent Setting	
Initial number of primary service nodes	α=12, β=14
Initial capital value	Bounded random within the range of [180,220].
Agent Type	Bounded random within [1,3].
Distance cost	Y=k*x(x>0, x indicates the distance moved.) In area1 and area4, k=1. In area2 and area5, k=1.3. In area3, k=1.7.
Operation cost	Bounded random within the range of [3,5] in area1 and area4. Bounded random within the range of [3,7] in area2 and area5. Bounded random within the range of [3,9] in area3.
Speed	Bounded random within the range of [1, 5].
Vision range	Bounded random within the range of [1 ,5].
Reproductive threshold	300
Reproductive Punishment	Y=k*d(x indicates the distance between parent agent and child agent, k=3)
Expansion threshold	N=25,V=4000 for area 2 and area 5. N=125,V=15000 for area 3.
Order Setting	
Complexity	Bounded random within the range of [1,3].
Order Type	Bounded random within the range of [1,3].
Order Value	Bounded random within the range of [10,30] when its initial complexity = 1. Bounded random within the range of [50,80] when its initial complexity = 2. Bounded random within the range of [70,100] when its initial complexity = 3.
Distribution of order	Orders are distributed randomly in five areas with centers of (59,79)(area1), (85,26)(area2),(125,54)(area3),(157,90) (area4), (180,36) (area5) respectively.
The generation rule of order	The market trends are represented by the function Y=N+M*sin(t). In area1 and area4, the reference value of order amount N is set as 200 and the range of fluctuation M is set as25. In case 1, the reference value of order amount N is set as 225 and the range of fluctuation M is set as 30 in area2, area3 and area5, In case 2, the reference value of order amount N is set as 350 in area3 when tick =280, and others are the same as case 1.
The profit sharing ratio	The ratio is 6:4 when the initial complexity of orders is 2. The ratio is 4:3:3 when the initial complexity of orders is 3.

(4) Evaluation indicators

The performance indicators introduced by the experimental system include entropy value H, which is used to measure the degree of disorder of service ecosystem; value consumption C, which is used to measure the operating costs of service ecosystem; and system value benefit V, which is used to measure the sustainability of service ecosystem.

B. Case 1: Ecosystem evolution in mature market

The evolution process of service ecosystem in mature marketing environment is shown in Fig.8.

(1) As shown in Fig.8-A, during the initial stage (from Tick=0 to Tick=80), there are only the primary service nodes in both service ecosystems and the nodes are only distributed in their core areas.

(2) As shown in Fig.8-B and Fig.8-C, during the early stage (from Tick=80 to Tick=160), both service ecosystems reach the expansion threshold simultaneously and the nodes enter into the adjacent areas.

(3) As shown in Fig.8-D and Fig.8-E, during the middle stage (from Tick=160 to Tick=320), service ecosystem α reaches the expansion threshold firstly and enter into the emerging service area.

(4) As shown in Fig.8-F, during the later stage (from Tick=320 to Tick=400), both service ecosystems is gradually taking shape. During the evolution, the number of nodes in both systems has been increasing. Because the control-dominated strategy has a risk sharing mechanism, the number of agents in the service ecosystem α is higher in high-risk areas.

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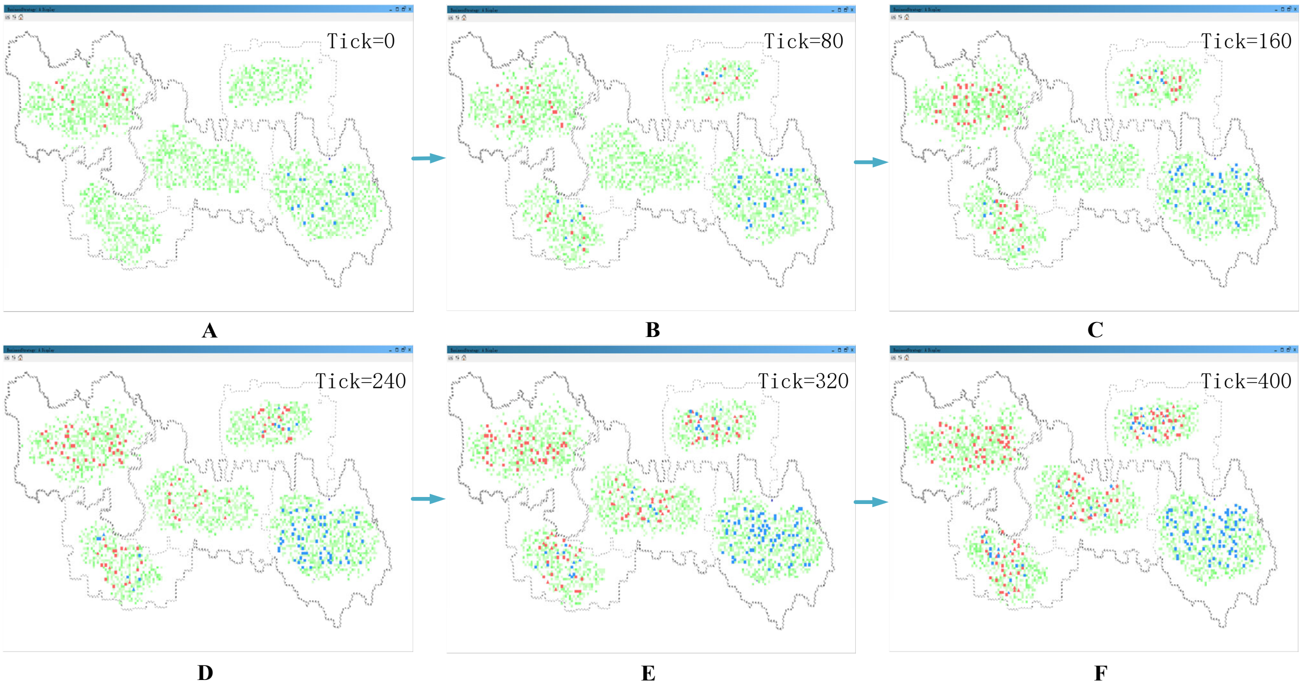

Fig.8 The evolution process of two service ecosystems in Case 1

Fig.9 gives a comparative analysis of the performance indicators of the two service ecosystems in Case 1. Fig.9-A gives the change of order quantity in all areas during the experiment period.

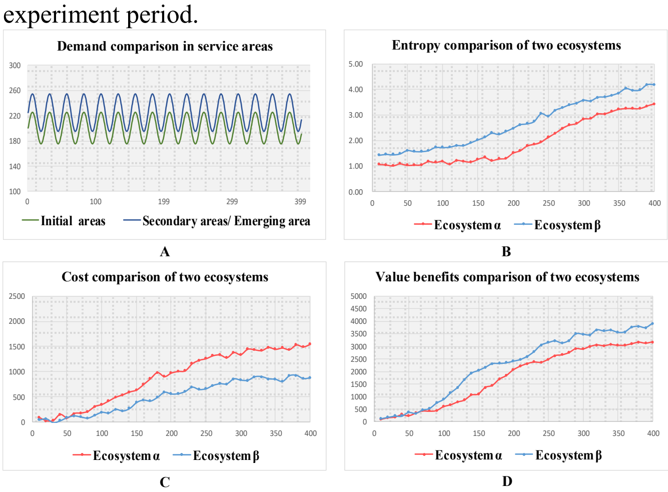

Fig.9 The performance comparison of two ecosystems

(1) Fig.9-B is the comparison of the entropy of two service ecosystems. With the increase in the number of service nodes, the diversity and disorder of the two systems are constantly increasing. Because ecosystem β adopts a random-dominated strategy, its ecological diversity is strong, and its entropy value is continuously greater than that of ecosystem α.

(2) Fig.9-C is the comparison of the cost of two service ecosystems. In a mature market environment, and management costs play a decisive role. Ecosystem α adopts the control-dominated strategy, which is more affected by management costs. During the experiment period, the system cost of ecosystem α and β increase slowly, and the cost value of α is higher than that of β. .

(3) Fig.9-D is the comparison of value benefits of two service ecosystems. In the same competitive environment, the higher the cost, the lower the net profit. So, the service ecosystem β has a higher value benefit in the evolution process.

Based on experiment analysis, it can be seen that in the mature market environment, the service ecosystem α is more orderly, but its value benefits and value growth trend are lower than that of β. The experiment results show that, the random-dominated strategy has better performances when the demand environment is stable. This result is consistent with the second conclusion of entropy model analysis.

C. Case 2: Ecosystem evolution in emerging market

The evolution process of service ecosystem in emerging market environment is shown in Fig.10.

(1) As shown in Fig.10-A, 10-B and 10-C， the early stage of this group of experiments is roughly the same as Case 1, and the differences are mainly in the middle and late stages of the experiment.

(2) As shown in Fig.10-D and Fig.10-E, during the middle stage (from Tick=160 to Tick=320), service ecosystem α reaches the expansion threshold firstly and enter into the emerging service area. In this area, the market demands show the explosive trend.

(4) As shown in Fig.10-F, during the later stage (from Tick=320 to Tick=400), both service ecosystems is gradually taking shape. The burst of demands causes more nodes in Case 2 than that of Case 1 in the same period. Because service ecosystem α adopts the control-dominated strategy, it has more agents in high-risk areas than ecosystem β.

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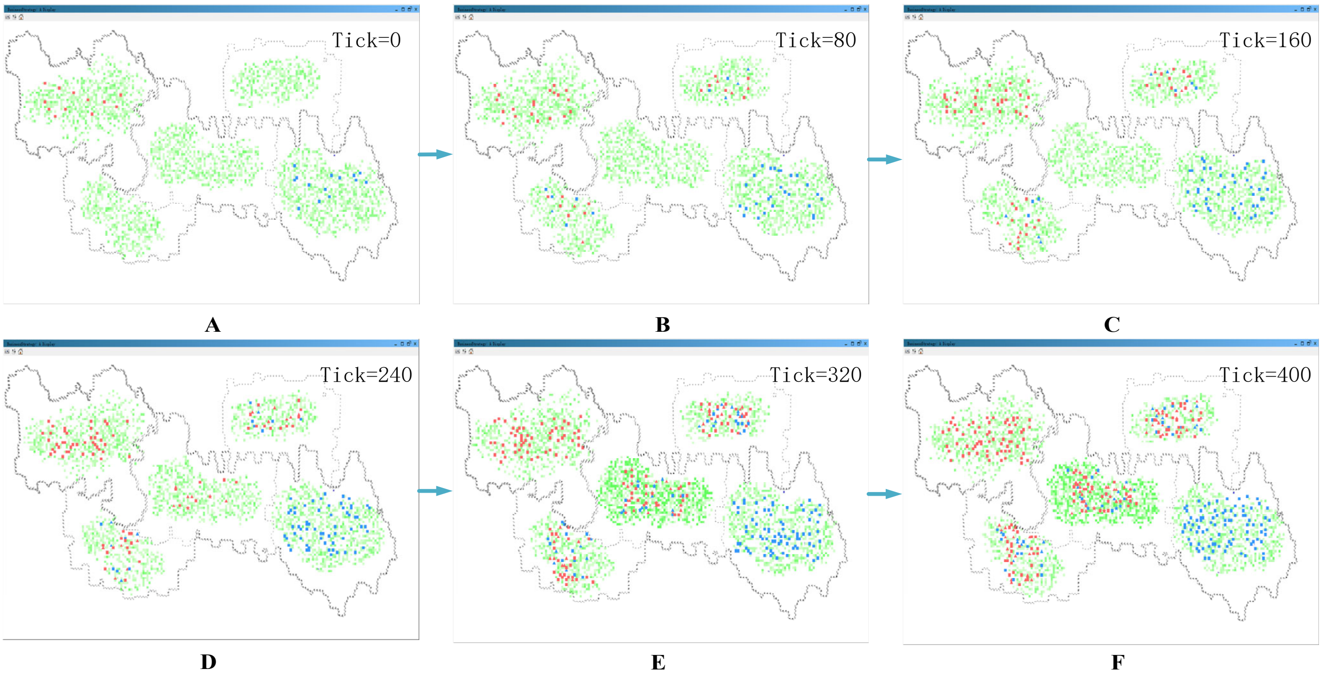

Fig.10 The evolution process of two service ecosystems in Case 2

Fig.11 gives a comparative analysis of the performance indicators of the two service ecosystems in Case 2. Fig.11-A gives the change of the order quantity in all areas during the experiment period, and in the middle and late stage, the demands explode in the emerging areas.

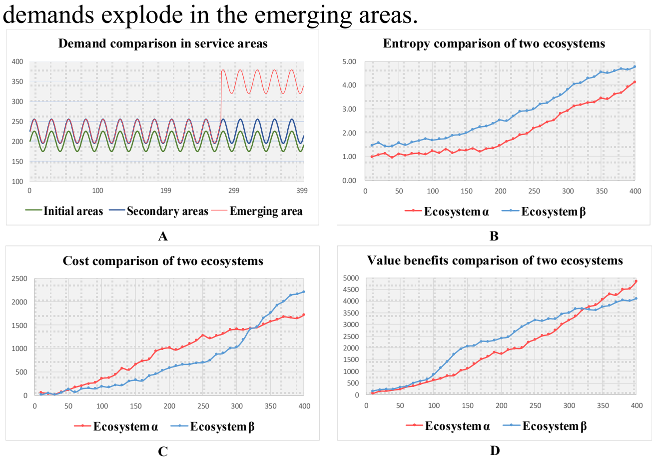

Fig.11 The performance comparison of two ecosystems

(1) Fig.11-B is the comparison of the entropy of two service ecosystems. The change trend of the entropy curve of the two systems is roughly the same as that of Case 1. But in this experiment, the number of nodes of the two systems is greater, and the ecological diversity is stronger. Therefore, Case 2 has a higher entropy value than Case 1.

(2) Fig.11-C is the comparison of the cost of two service ecosystems. In the early stage of the experiment, demand quantity is stable, and management costs steadily increase with the number of nodes. At this stage, the main share of overall costs is management costs. In the middle and late stages of the experiment, due to the outbreak of demand, matching costs increase significantly. Ecosystem β adopts random-dominated strategy, which is more affected by matching costs. This leads to the total cost of ecosystem β overtaking ecosystem α in the later stage of the experiment.

(3) Fig.11-D is the comparison of value benefits of two service ecosystems. The cost of service ecosystem is inversely proportional to value benefit. In the latter part of Case 2, the cost of ecosystem β surged and surpassed ecosystem α. So, the value of ecosystem α finally surpassed that of ecosystem β.

Based on experiment analysis, it can be seen that in the emerging market environment, the value benefits and value growth trend of service ecosystem α are also greater than that of β. The experiment results show that, the control-dominated strategy has better performances when the demand environment is explosive. This result is consistent with the third conclusion of entropy model analysis.

In Case 1, the service ecosystem α with lower entropy has lower value benefits. In Case 2, the service ecosystem β with higher entropy has lower value benefits. This shows that too high or too low entropy is not conducive to creating value. The system whose entropy is closer to the optimal entropy value has higher value benefits, which is consistent with the first conclusion of the value entropy model.

VI. Discussion

This section will compare the differences between Alibaba and Tencent in the construction of the service ecosystem to prove the validity of the experimental results. The relevant data comes from their financial reports, official website and related service data in the APP Store.

As shown in Fig.12, the construction processes of service ecosystem of the two Internet enterprises can be approximately divided into three stages. In the first two phases, both companies focused on their core areas and related business areas. In the third phase, New retail, Mobile payment and other emerging areas (e.g. Cloud computing and IoT platforms) have brought a new round of development opportunities for the two enterprises.

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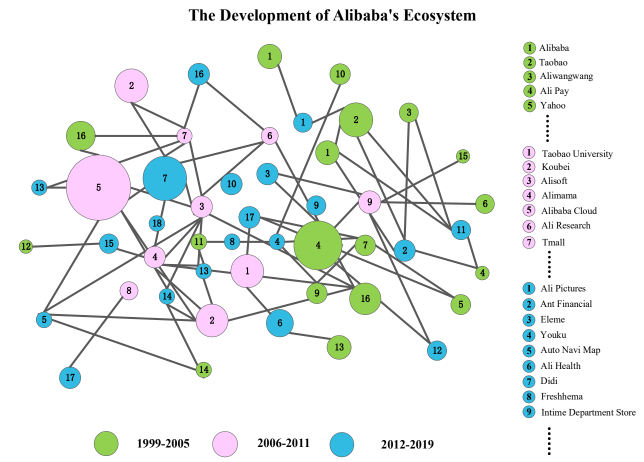
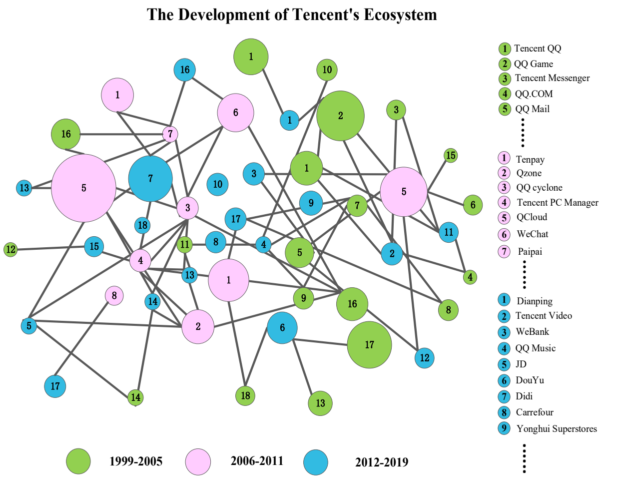


- **The first phase**: Alibaba focused on its e-commerce core business, such as Alibaba and Taobao trading platform.
- **The second phase**: Alibaba extended its businesses into related areas, such as Koubei and Tmall. At the same time, it increased infrastructure investment and established Ali Cloud, Ali Research and Ali university.
- **The third phase**: Alibaba extended its business to cross-domain or emerging markets, such as finance, education, health care, living, new retail, etc.



- **The first phase**: Tencent has laid a foundation in instant message software, such as QQ, QQ email, etc.
- **The second phase**: Tencent developed related services such as WeChat and QQ space, and established Tencent Cloud company.
- **The third phase**: Tencent extended its business to cross-domain or emergingmarkets, such as finance, game, video, new retail, etc.

Fig.12 The construction process of service ecosystem of Alibaba and Tencent

The different development strategies mentioned in the experiment are also reflected in the operation of the two Internet companies. Alibaba's strategy is control-dominated, and it emphasizes the full control over nodes in the ecosystem. It takes e-commerce business as the core of the whole ecosystem and all other businesses are built around this core , including finance, logistics, cloud computing and other related fields. In order to ensure the deep convergence of its core area and emerging areas, Alibaba either set up the company itself or bought other companies wholly, such as Cainiao Logistics, Qunar, etc. This strategy has a relatively strong execution power and can continuously invest in emerging areas.

On the other hand, Tencent has adopted a random-dominated strategy, emphasizing itself as the ecosystem's infrastructure. It empowers related enterprises with the resources needed to form a loose community of interests. Tencent's advantage lies in online traffic. It enters areas where it is not good at by investing in shares, such as E-commerce, Sharing economy, O2O life service, and so on. The advantage of this strategy is less investment and relatively low risk. However, it is difficult to make long-term investment in some areas with uncertain prospects, and some valuable opportunities may be missed.

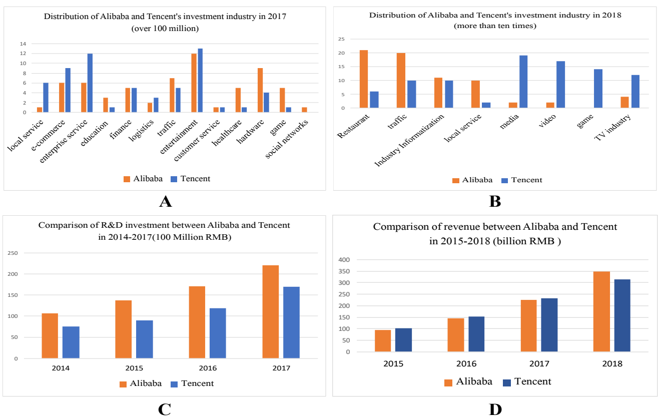


Fig.13 The comparison of financial data between Alibaba and Tencent

As shown in Fig.13-A and 13-B, the ecosystems of Alibaba and Tencent have shown an increasing tendency to overlap with each other in business areas. Alibaba's development strategy requires more investment in the early stage. As shown in Fig.13-C, since 2014, Alibaba's investment has continued to be higher than that of Tencent. Figure 13-D shows the revenue comparison between Alibaba and Tencent from 2015 to 2018. Before 2017, the emerging markets have not yet been broken, and market demand is relatively stable. Therefore, Tencent has an advantage in terms of revenue. Subsequently, cloud computing and mobile payment businesses experienced explosive growth. In 2018, Alibaba's revenue exceeded Tencent's, and its control-dominated development strategy played a huge role in it, which is consistent with the analysis results of our entropy model.

VII. Conclusion

As a product of service-based economy and software service technologies, service ecosystem is a complex socio-technical system. Currently, the service ecosystem has emerged in many areas, such as manufacturing, e-commerce, and software. In order to better study and manage the complex and dynamic relationships between the service nodes in the ecosystem, this paper proposes a value entropy model from the perspective of value network, including entropy measurement, value analysis and operation strategy. The above work can provide new ideas and tools for the operation analysis and optimized governance of service ecosystems.

The value entropy model does not depend on specific domain attributes, which can make unified and reasonable evaluation for different types of service ecosystems. Moreover, the model does not depend on the system scale, which provides a basis for studying small and medium-sized ecosystems, such as Alipay's service ecosystem, WeChat's small program ecosystem, etc. However, the current entropy model treats all service nodes in the service ecosystem as discrete, without considering the cooperative relationship between them. The model needs further improvement to be more consistent with the real situation of the service ecosystem. In addition, the construction of the computational experiment environment also needs to reduce the difficulty to improve the user's convenience.

The purpose of interpreting phenomena is to predict, while the purpose of prediction is to governance. In order to promote the service ecosystem to evolve in the expected direction, many topics need further research. In the future, we will use the continuously optimized entropy model to analyze the evolution of service ecosystems with different sizes in different fields. In the field of mobile Internet services, the case of some emerging companies defeating industry giants has attracted our attention, such as ByteDance vs Tencent, Meituan vs Alibaba, and so on. We hope to reveal the explicit and implicit reasons behind theses phenomena, in order to provide the optimized evolution path of service ecosystem in the specific context.

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