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Analysis on supply–demand system of automotive manufacturer–supplier with Synergetics

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Abstract
The supply–demand system (S–DS for short below) of automotive manufacturer–supplier (AM–S for short below) is a network system which consists of demand subsystem and supply subsystem. The supply–demand relationships reflect the partnership between AM–S. There is a need for coordination and cooperation between two subsystems in order to achieve the balance between the supply and demand. From the perspective of Synergetics, this paper analyses how the control parameters of S–DS which are called synergetic order parameters play the main control role to make S–DS reach the cooperative state, and discusses the discipline of the coordinated evolution in systems. Finally, the synergetic degree model is put forward to demonstrate the coordinative management effect of S–DS.

Keywords Automotive manufacturer–supplier · Supply–demand system · Exogenous variables · Endogenous variables · Synergetic order parameter · Synergetic degree

1 Introduction

The supply–demand system (S–DS for short below) of the automotive manufacturer–suppliers (AM–S for short below) is a network system which consists of demand subsystem and supply subsystem. It is one of the most complex systems in manufacturing industry. It consists of one to two assembly plants or vehicle factories, and its supplier system consists of five to six suppliers. The S–DS defined in this article is limited to the S–DS between the manufacturer and the first-tier suppliers. It can be divided into supplier-oriented supply subsystem and automotive manufacturer-led demand subsystem. The partnership between the AM–S is reflected by the supply and demand relationship between the two parties. The synergy of the two subsystems helps to achieve the goal of the two sides under the partnership, and also improves the competition of the automobile manufacturing supply chain.

There is a need for coordination and cooperation between the two subsystems in order to achieve the balance between the supply and demand. The target of supply–demand balance is to coordinate the needs of the customers, the needs of manufacturers and the supplier's material flow and supply. That is, the flow of materials in the supply chain is orderly. At the right time and at the right place, the supply quantity of upstream nodes is equal to the demand quantity of downstream nodes, including the corresponding varieties, quality and price [1, 2]. The main reason why the S–DS in imbalance is the shortage of supply availability or the suppliers cannot make quick-response to the changed order [3]. And the collaborative procurement mode can achieve the target of just-in-time purchase, to meet the quantity and quality requirement. Meanwhile it is conducive to improve the supply availability and the quick-response ability, to deepen the relationship between the automotive manufacturer and suppliers. Under the premise of partnership between AM–S, the collaborative procurement is the supplier dispatches the components and parts with correct quantity and good quality to the designated location within a specified period

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of time in accordance with the real-time order. The model requires close cooperation between AM–S, and the supplier needs quick and real-time response to the demand of the automotive manufacturer.

The basic principles of Synergetics are used in the collaborative procurement model. Synergetics is a subject which studies the common features and the collaborative mechanism in different systems. It explores the law of mutual competition and cooperation between subsystems with regard to nature and society [4]. A system can be divided into several subsystems, and the subsystems are often synergistic under certain conditions. Moreover, the synergies between subsystems are governed by the same principle, independent of the nature of the subsystems [5].

The application of Synergetics in automotive industry is distributed in all aspects of the automotive manufacturing process, such as collaborative design [6–10], collaborative procurement [11], collaborative manufacturing [11, 12] and collaborative commerce [13–16].

Collaborative design and concurrent engineering are applied in the design of Ford2000C3/P, Chrysler Viper, and Renault etc., which make the production reaches a predetermined volume in a shortened time from 37 months to 19 months, only 50% of the original. GM Pontiac Le Mans models apply global collaborative manufacturing, the car is assembled in Korea, engine, axle, and circuit are supplied by Japan, the design work is done in Germany, some other parts come from Taiwan, Singapore and Japan, Spain offers advertising and marketing services, complete data is processed in Ireland and Barbados. Some services such as strategic research, lawyers, banking and insurance are provided by Detroit, New York, and Washington. Only about 40% of the total cost is generated in the United States mainland. [11] Collaborative thought affects the organization mode, the product operation mode and even the business mode of automobile manufacturing, thus affects the cooperative relationship between enterprises on automobile supply chain node, that's why more and more entrepreneurs and scholars pay their attention to it.

Kaur Arshinder [17] reviewed literatures on supply chain coordination management in a book named *Supply Chain Coordination under Uncertainty* [18]. They summarized the aspects of supply chain coordination mechanisms, managing uncertainty and research directions with 169 articles in 16 journals from 1991 to 2001. Martin Albrecht [19] studied the integrated operational plans for all functional areas and members within a supply chain coordination planning. John A. Muckstadt [20] established a set of guiding principles for the effective design and execution of supply chain systems. These principles suggest why, what, and how collaborative relationships should be constructed. Studies on supply chain coordination under different demand patterns are as follow: price sensitive demand under supply interruption risk [21], demand disturbance management with nonlinear demand function [22], fixed interval delivery and linear demand [23], demand satisfaction using a full online optimal control method [24], stochastic demand [25], and optimal production policy under lumpy demand [26]. Sunil Luthra [27, 28] and Ki-Hoon Lee [29] studied the supply chain coordination with green and sustainable development in automobile industry.

From the above it can be seen that a lot of researches on supply chain coordination management. They mainly apply uncertainty theory and inventory control theory focusing on supplier and retailer. The coordination studies on automobile manufacturing industry or from the point of view of Synergetics are relatively few. For the purpose of enhancing supply capacity and quick response ability, and making S–DS achieve a collaborative state, we need to define the control variables, and determine the synergetic order parameter to control S–DS with synergy. According to the basic principle of Synergetics, this paper attempts to analyse the evolution laws of S–DS of AM–S, and discuss the coordination mechanism, aiming at studying the complex uncertain relationships of them.

2 Synergetic variables analysis of S–DS

2.1 Determination of exogenous variables

The exogenous variables of Synergetics are the external control parameters of a system, and the general terms of material flow, parameter flow, information flow that a system imports from external environment. They're the parameters which cannot be ignored in the whole process of evolution of a system.

According to the Synergetics modelling standards, exogenous variables are those which have the most direct influences on the development of the S–DS of AM–S. The total amount of social investment and the application level of technology are the most important external control parameters. The total amount of social investment of a system refers to the external investment, it is an absolute value, such as the capital support from the government to automotive industry; the investment which accumulates by enterprise itself for its own development, or comes from system inside are not exogenous variables.

2.2 Determination of endogenous variables

The endogenous variables are those which are determined by synergism between subsystems reflecting the characteristics and status of a system. Endogenous variables can be further divided into slow variable (also called order parameter) and fast variable. The slow variables dominate the evolution of a system, and the fast variable is controlled by slow variable, but the latter is an indispensable part to system evolution. The fast variable has bigger critical damping and faster attenuation, and cannot afford obvious function to system evolution; the slow variables present a phenomenon without critical damping, and get response from most of subsystems to lead the behaviour of a system, reflecting the evolution process and development of a system definitively [4].

The balance of supply and demand of AM–S can be realized from three aspects: quantity, quality, and just-in-time [11]. Seen from the internal control variables of the S–DS of AM–S, order quantity is the main control variable in the whole S–DS, because the decision which manufacturer makes depends on the market demand of users at present, it changes in species and quantities following the needs of users.

2.3 Determination of synergetic order parameter

In a system which is far from equilibrium state, there are always spontaneous and independent movements without rules of subsystems, while they receive common function from each other, in other words, synergy movement exists between subsystems [30]. The order parameter comes from the collaboration between subsystems, and it dominates the behaviours of subsystems at the same time. Synergy contains two meanings: one is the macroscopic and ordinal structure that subsystems produced by collaboration; the other is that sometimes there may be several order parameters in a system at the critical point, they will coordinate automatically with each other to control the system and decide the macroscopic structure jointly [5].

The variables this paper defines in S–DS are followed: Q means the basic order quantity of automotive manufacture; f_1 means the coefficient of supply quality level and f_1Q means the supply quantity according with certain quality level; q_1 means change of order, positive or negative; f_2 means the coefficient of just-in-time service level of S–DS; q_2 means change of satisfaction of just-in-time service.

Considering the change of S–DS, the endogenous variables are q_1 and q_2. Within a period of time, q_1 will be stable as slow variable if automotive manufacturer's plan of one kind of product does not change, and supplier maintains certain manufacturing technology level. When competition of market grows, automobile manufacturer and supplier will pay attention to the improvement of their own competitiveness at the same time, suppliers endeavour to improve productivity and technology level to ensure the quality of products, and build good partnership with manufacturer to achieve monophyletic supply as far as possible, that will improve the synergy degree and just-in-time service satisfaction with manufacturer, so q_2 is fast variable which changes rapidly.

To sum up, we define f_1f_2Q as the order parameter of the S–DS of AM–S. It is a comprehensive control variable of considering the supply capacity, supply quality level and the just-in-time service level.

3 Synergetic evolution analysis of S–DS

3.1 Order parameter equation of S–DS

S–DS evolves with the changes of exogenous variables and endogenous variables. This paper establishes comprehensive order parameter equation and analyses the evolution law of a system based on the theory of Synergetics. It is the basic differential equation form of Synergetics [31, 32], which is widely used in the fields of physics, chemistry, electronic engineering and electronics, biology, computer science, economics, ecology and sociology [33, 34].

γ_1 means the influence degree of technical factors of S–DS on the f_1Q which means the supply quantity according with certain quality level; γ_2 means the influence degree of technical factors of S–DS on the satisfaction degree of just-in-time service. Such as the advanced degree of the suppliers' technology level of hardware production equipment or the information exchange platform of AM–S which influences the operation of a system directly. It considers the comprehensive factors including negative effects, such as low level of production technology leads to poor production quality, so γ_1 and γ_2 are vectors.

K_1 means the influence of investment on f_1Q, K_2 means the influence of investment on the satisfaction degree of just-in-time service. The investment to production will prompt the quantity and the yield to increase, such as introducing new equipment and new manufacturing technology. It will also promote the coordination between automotive manufacturer and suppliers, and bring about more benefits. So K_1 is positive.

In the S–DS of AM–S, f_1Q relates to technical factors and investment, which can be expressed by $(\gamma_1 + K_1)q_1$. The expression $-\alpha q_1 q_2$ means the influence of the synergy degree of AM–S on order quantity. It is negative because the synergy can reduce each batch. Among them, α is the synergetic coefficient, the higher value of the number, the stronger synergy of the system, the bigger ordered degree. So the Eq. (1) is established as follow.

$$\dot{q}_1 = (\gamma_1 + K_1)q_1 - \alpha q_1 q_2 \tag{1}$$

Just-in-time service level relates to technical factors itself and investment similarly. Usually, the total social investment is a constant within particular times, and different production plans have different capital allocation plans. For the entire supply chain, the investment of improving production capacity and enhancing the technical level of AM–S themselves and the investment of coordinative management between them will follow the principle of same-total-sum-game. The latter's investment reduces when the former's investment increases, the expression $-\beta q_1^2$ used to show the investment reducing effect of the latter. The Eq. (2) is established as follow.

$$\dot{q}_2 = (\gamma_2 + K_2)q_2 - \beta q_1^2 \tag{2}$$

According to the requirement of system research with Synergetics, when slow variable q_1 does not exist or breaks down, q_2 is stable with damping, it will return to the stable state of $q_2 = 0$ due to the influence of damping, and $\gamma_2 + K_2 > 0$ is required [30]. In order to analyse the development and evolution of the system, it needs to ensure the availability of the adiabatic elimination technique. Therefore, it assumes that the damping of q_2 far greater than slow variable q_1's. That is:

$$\gamma_2 > > \gamma_1 \tag{3}$$

It means that the change and the attenuation of just-in-time service satisfaction are much faster than $f_1 Q$, and the adiabatic approximation is established. Here, it commands that $q_2 = 0$. The result of the equation $(\gamma_2 + K_2)q_2 - \beta q_1^2 = 0$ shows as follow.

$$q_2 = \frac{\beta}{\gamma_2 + K_2} q_1^2 \tag{4}$$

Formula (4) shows that the change q_2 of just-in-time service satisfaction is controlled, dominated and enslaved by slow variable q_1, which q_2 acts upon q_1 according to the instruction of q_1. Slow variable q_1 decides the behavior of q_2. It means the manufacturer's order activity affects suppliers' produce activity and the partnerships between them, and determines the change of sequence and degree of order to the whole S–DS. But fast variable q_2 reacts to the slow variable q_1 at the same time, which also influences and restricts the development and function of q_1. It means the suppliers' production capacity and the manufacturer's just-in-time coordinative degree influence the production and demand of manufacturer also. Substituting formula (4) to (1), we get the order parameter evolution equation of S–DS such as formula (5).

$$\dot{q}_1 = (\gamma_1 + K_1)q_1 - \frac{\alpha\beta}{\gamma_2 + K_2} q_1^3 \tag{5}$$

We get the potential function of the evolution equation using $\dot{q}_1 = -\partial V(q_1)/\partial q_1$.

$$V(q_1) = -\frac{\gamma_1 + K_1}{2} q_1^2 + \frac{\alpha\beta}{4(\gamma_2 + K_2)} q_1^4 \tag{6}$$

Because $\gamma_2 + K_2 > 0$ is known, it analyses the curve shape of potential function with different quadratic term coefficients [30]. The balance point of the potential is determined by $\dot{q}_1 = 0$.

3.2 Analysis on synergetic variation of S–DS

1. The curve of potential function shapes as Fig. 1 when $\gamma_1 + K_1 < 0$.Seen from Fig. 1, the balance point of the potential which falls on $q_1 = 0$ is only one this moment. It is a stable point of system. The situation is the state in the S–DS of AM–S that there's a very small amount investment into the whole system and the information technology and control method between manufacturer and suppliers are laggard.

   The actual condition is similar to the movement of particle shown in Fig. 1, which is a particle in the potential energy valley. The particle represents the demand quantity of automotive manufacturer in the S–DS. It may deviate from the bottom of valley due to random force, but it will return ultimately. That is there may be a minimal change of the actual demand due to some reasons, but it will maintain original condition or be in a fixed trajectory most of the time. In fact, in the case of a system with small investment and laggard production technology, the turnover of AM–S will maintain a certain value. Then, the state which S–DS is in is low productivity and no cooperation between both sides appears.
2. The curve I of potential function shows in Fig. 2 when $\gamma_1 + K_1 > 0$. It indicates the state in which the S–DS of AM–S with higher synergetic degree. Then there are three potential points of potential function at this time,

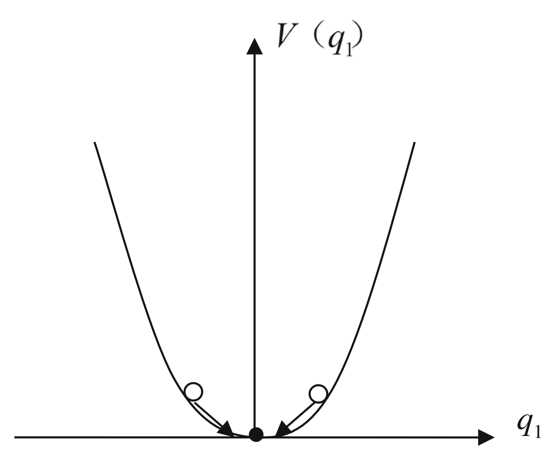

Fig. 1 Curve of potential function when $\gamma_1 + K_1 < 0$ and $\gamma_2 + K_2 > 0$

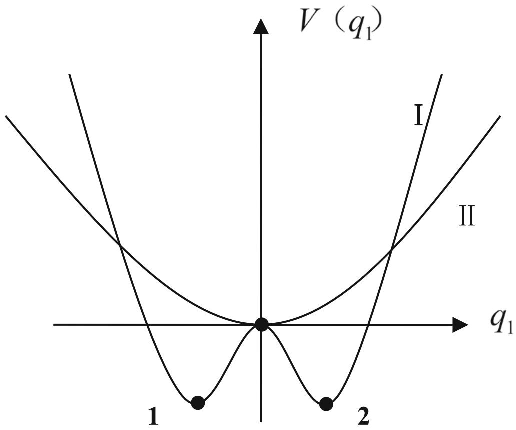

Fig. 2 Curve of potential function when $\gamma_1 + K_1 > 0$ and $\gamma_2 + K_2 > 0$

which are $q_1 = 0$ and $q_1 = \pm\sqrt{|\gamma_1 + K_1|(\gamma_2 + K_2)/\alpha\beta}$. Obviously, the zero point is unstable, and point 1 and point 2 are two steady points which correspond to two steady states. The phenomenon is called the symmetry of instability that changes from one stable point into two steady points.

The system may deviate from the state of $q_1 = 0$ due to the random fluctuation, and leap from the unstable state to one of the two steady states, that is the particle will in the position of 1 or 2. Because of q_1 representing the synergy degree of the system and the stable state appearing within a certain period, it's the evolution process of a system that the old structure gives way to new structures.

Corresponding to the situation of S–DS, the production and information technology improve continuously along with the increase of system investment, and the whole system has changed fundamentally. The state that with low work efficiency and uncompetitive supply chain is broken, which changes to that with stable market demand and steady development of S–DS.

According to formula (4), it gets $q_2 = 0$ when $q_1 = 0$. It shows that the fast variable has no effect when there's no slow variable. Then in the condition of no order of automotive manufacturer, there's no relationship occurred between supply system and demand system, and mutual cooperation is also out of the question.

In the process of $\gamma_1 + K_1$ changing from negative to positive, the curve becomes more and more flat which is shown as curve II in Fig. 2. In this case, the restoring force of particle becomes smaller, thus the return speed of particle becomes lower too. The phenomenon is called "critical slowing down" in Synergetics [30]. In S–DS, following the increase of investment and the improvement of production technology within a period of time, the production tends to stable gradually, and the demand is stable gradually on the whole supply chain with which the uncertainty of supply and demand reduces. But at the same time, demand is not static either. It changes occasionally by influence of random fluctuation force. The moving range of particle also becomes wider when potential curve sharps flatter. The phenomenon is called "critical fluctuations". When the demand of automotive manufacturer is certain, the key is whether the suppliers can finish the delivery just-in-time, under the premise of ensuring the quantity and quality of products, so to maintain the partnership. At this time, the system is in critical condition.

3. In the process of the evolution of system, with the phase transition proceeds starting from the critical point $q_1 = 0$, the curve of potential function presents two increasing extreme values $q_1 = \pm\sqrt{|\gamma_1 + K_1|(\gamma_2 + K_2)/\alpha\beta}$. The phenomenon of one solution divided into two solutions at the critical point is called "bifurcation phenomena" [35]. The curve which sees the balance position q_1 as a function of $\gamma_1 + K_1$ shows in Fig. 3.

The $q_1 = 0$ when $\gamma_1 + K_1 < 0$; and bifurcation phenomena appears when $\gamma_1 + K_1 > 0$, a_0 shows the original state in Fig. 3; $a_0 \sim a_1$ shows that the system leaves the equilibrium state and is in the linear area of unbalance. a_1 is the bifurcation point which is unstable; $a_1 \sim b_2$ expresses the instability of nonlinear relationship of the system. With the investment growing and the technical level of supply chain improving continually and the effect of the external fluctuation force, there's tiny deviation of collaborative benefits to the system integrity, which magnifies rapidly through the organizational process of the system itself. The synergetic effect enhances collaborative benefits, and then drives the evolution of S–DS to a new orderly structure further.

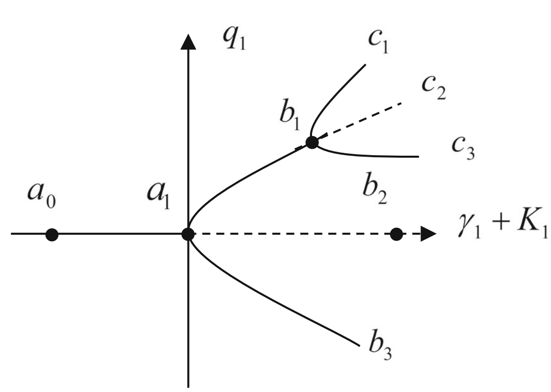

Fig. 3 Curve of potential function of $q_1 \sim (\gamma_1 + K_1)$

Two bifurcations of $a_1 \sim b_1$ and $a_1 \sim b_3$ in Fig. 3 shows the two different states of system collaborative benefits respectively which self-organization engenders. They are caused by different order parameters. In the section of $a_1 \sim b_1$, some fluctuation forces affect the system so as to make the competition and the collaborative benefits of the system improved greatly, such as the manufacturer or suppliers use some advanced production technology, or logistics industry improves the service level, or transportation industry standardizes service, therefore the system enters into the state of continuous and steady development; In the section of $a_1 \sim b_3$, some fluctuation forces affect the system so as make it enter into the state of attenuation trend, such as the rising prices of raw materials or most other competitors improve themselves, which lead to the increase of costs and the damage of collaborative benefits. And along with the evolution and development of system, when the external environment changes again, the collaborative benefits jump to a higher level from a certain level, which is shown as in Fig. 3 that $a_1 \sim b_1$ leap to $a_1 \sim c_2$. Then system reaches a new orderly structure again.

4 Synergetic measure analysis of S–DS

We establish the order degree model and the synergetic degree model based on the research on the coordinating model for the co-system of science and technology and economy [36–38].

4.1 The order degree model of subsystems

$e_1 = (e_{11}, e_{12}, \ldots, e_{1n})$ are defined as the variables of supply subsystem, which are some indicators describing the operating mechanism and operational status of subsystem, where $n \geq 2$, $\beta_{1i} \leq e_{1i} \leq \alpha_{1i}$, $i \in [1,n]$. $e_{11}, e_{12}, \ldots, e_{1k_1}$ are positive indicators if the values of are bigger and then the values of order degree are higher. In contrast, $e_{1k_1+1}, \cdots, e_{1n}$ are negative indicators. Then $u_1(e_{1i})$ is the order degree model of e_{1i} in formula (7), where $u_1(e_{1i}) \in [0,1]$. Obviously, the size of the value reflects the degree of contribution to the system orderly. In the actual system, there will be indicator e_{1i}, which means the value too large or too small is not good, and should concentrate around a particular point, such as the actual supply point. For such indicator, it is always possible to satisfy the formula (7) by adjusting its range of limit values.

$$u_1(e_{1i}) = \begin{cases} \dfrac{e_{1i} - \beta_{1i}}{\alpha_{1i} - \beta_{1i}}, i \in [1, k_1] \\ \dfrac{\alpha_{1i} - e_{1i}}{\alpha_{1i} - \beta_{1i}}, i \in [k_1 + 1, n] \end{cases} \tag{7}$$

As a whole, the “total contribution” of variables e_1 to the degree of supply subsystem can be achieved through integration of $u_1(e_{1i})$. This model is integrated by linear weighted summing scheme, in which the weights of each indicator can be determined by the method. Thus $u_1(e_1)$ is called the order degree of the e_1 that seen in formula (8).

$$u_1(e_1) = \sum_{i=1}^{n} \omega_i u_1(e_{1i}), \omega_i \geq 0, \sum_{i=1}^{n} \omega_i = 1 \tag{8}$$

Similarly, $e_2 = (e_{21}, e_{22}, \ldots, e_{2m})$ are defined as the variables of demand subsystem, where $m \geq 2$, $\beta_{2j} \leq e_{2j} \leq \alpha_{2j}$, $j \in [1,m]$, and $u_2(e_2) \in [0,1]$.

4.2 The synergetic degree model of system

For a given initial time or a specific time period t_0, the order degrees of the two subsystems are $u_1^0(e_1)$ and $u_2^0(e_2)$. Then for a time or time period t_1 in development and evolution process, the order degrees of the two subsystems are $u_1^1(e_1)$ and $u_2^1(e_2)$. If $u_1^1(e_1) \geq u_1^0(e_1)$ and $u_2^1(e_2) \geq u_2^0(e_2)$ fulfill at the same time, then the S–DS develops co-ordinately from time t_0 to t_1. The synergetic degree model of system displays in formula (9) and formula (10) [39, 40].

$$U = \lambda \sqrt{\left|u_1^1(e_1) - u_1^0(e_1)\right| \left|u_2^1(e_2) - u_2^0(e_2)\right|} \tag{9}$$

$$\lambda = \begin{cases} 1 \quad u_1^1(e_1) \geq u_1^0(e_1) \ \ and \ \ u_2^1(e_2) \geq u_2^0(e_2) \\ \qquad\qquad\qquad\qquad -1 \quad others \end{cases} \tag{10}$$

Where:

1. Evidently, $U \in [-1,1]$, the degree of collaborative development of the system follows the value of U.
2. $u_1^1(e_1) - u_1^0(e_1)$ reflects the extent that the order degree changes from time t_0 to t_1.
3. The synergetic degree U takes two subsystems into account. If the order degree of one subsystem increases more and another subsystem increases less or even decreases, the whole system cannot be in a fine coordinative state or even no coordination, the performance of the synergetic degree U is small or negative.

4.3 A case study on synergetic measure analysis

In this case, it is assumed that the supplier is fixed within a year for a car manufacturer to supply some kind of parts of a car, and the car manufacturer orders such parts from the supplier. The indicators of two subsystems are shown in

Table 1 Indicators system of supply subsystem

Indicators	Unit	Indicator description
e_{11} the quarterly average supply	piece	Refers to the average actual supply of spare parts each quarter
e_{12} the rate of delivery on time	%	Refers to the just-in-time service level of supplier. It's high generally because of signboard production and distribution of logistics centre
e_{13} the rate of warehouse utilization	%	Refers to the parts storage time and the response level of supplier
e_{14} the order completed time	day	Refers to the time from the supplier receives the order to the end of all parts produced by mass. The model uses the average order completion time per lot
e_{15} the rate of defective product	%	Refers to the probability for each batch of products appear waste and defective. It's generally related to the level of production technology

Table 2 Indicators system of demand subsystem

Indicators	Unit	Indicator description
e_{21} the quarterly average demand	piece	Refers to the average actual order quantity of spare parts each quarter
e_{22} the rate of warehouse utilization	%	Refers to the relationship between procurement activities and production activities, reflects the synergetic level among car manufacturers
e_{23} the rate of warehouse turnover	%	Refers to the frequency of purchase of spare parts for car manufacturers
e_{24} the rate of receiving goods correctly	%	Refers to the logistics service level of car manufacturers, reflects the synergy of S–DS
e_{25} the average order lead time	day	Refers to the safe procurement lead time for production, reflects the level of collaborative procurement

Tables 1, 2. The data in Table 3 are two sets of indicators data of a car manufacturing enterprises and their suppliers.

Four main steps will be followed in synergetic measure analysis.

Step 1 Basic data standardization

Before determining the weight of the indicators, the basic data needs to be standardized, so that the different units and different magnitudes can be dimensionless. We standardize data using Z-score standardization.

Step 2 Determination of the weight of the indicators

We determine the weight of the indicators ω using the correlation matrix weighting method [41]. The results that calculated by SPSS are shown in Table 4.

Step 3 The synergetic degree calculation

The order degree of subsystems u_1,u_2 and the synergetic degree of system U which are calculated by formula (7) to (10) list in Table 5. Where, U is calculated on a basis of zero quarter assuming that the order degrees of the subsystems are zero in zero quarter.

Step 4 Analysis of calculation results

The trends of u_1,u_2 and U are shown in Figs. 4, 5.

Table 3 Basic data of subsystems

Quarters	e_{11} (piece)	e_{12} (%)	e_{13} (%)	e_{14} (day)	e_{15} (%)	e_{21} (piece)	e_{22} (%)	e_{23} (%)	e_{24} (%)	e_{25} (day)
1st	2629	97	94	2.4	0.6	2629	90	92	96	1.8
2nd	5816	97	95	2.0	0.4	5816	94	92	96	1.3
3rd	18074	99	99	1.4	0.3	18074	97	93	96	1.2
4th	11321	100	99	1.4	0.2	11321	98	94	99	1.1
Upper limit α	18074	100	100	2.5	0.6	18074	100	95	100	2.0
Lower limit β	2629	95	90	1.0	0.1	2629	90	90	95	1.0

Table 4 The weights of the indicators

Indicators	e_{11}	e_{12}	e_{13}	e_{14}	e_{15}	e_{21}	e_{22}	e_{23}	e_{24}	e_{25}
R	3.4932	3.6832	3.7589	3.7881	3.6900	2.5017	3.3761	3.3153	2.3658	3.0852
ω	0.1897	0.2000	0.2041	0.2057	0.2004	0.1708	0.2305	0.2264	0.1616	0.2107

Table 5 The order degrees of subsystems and the synergetic degree of system

Quarters	1st	2nd	3rd	4th
u_1	0.1717	0.3742	0.8350	0.7817
u_2	0.1457	0.4074	0.6590	0.7591
U	0.158	0.230	0.340	− 0.073

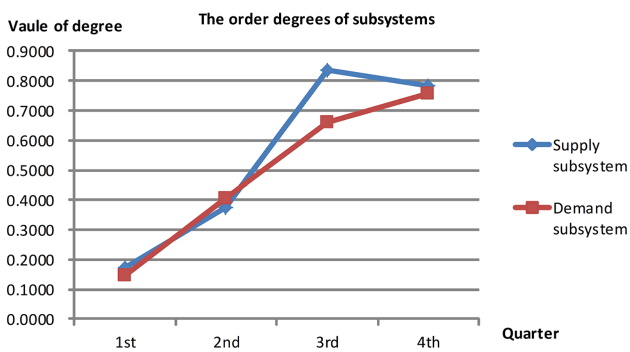

Fig. 4 Curve of the order degrees of subsystems

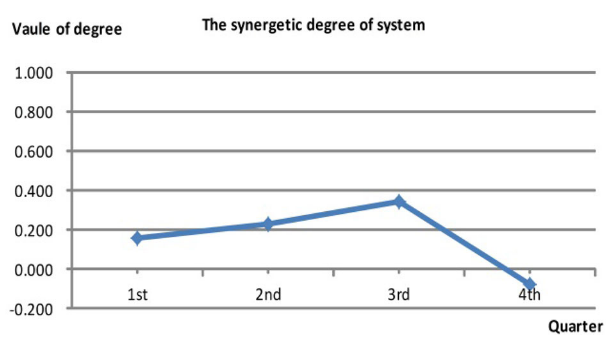

Fig. 5 Curve of the synergetic degree of system

It can be seen from Fig. 4 that the order degrees of two subsystems are between 0.14 and 0.84, indicating that there're synergies inside the subsystems. Overall, the average internal collaborative management level of two companies is high.

For supply subsystem, the order degrees of one to three quarters grow fast from 0.17 to 0.84, and reach the highest throughout the year, among them the order degree curves of the first and third quarters vary significantly. With the advent of busy season in car production, the business of supplier becomes bustling following the gradually increased orders. Simultaneously, the cooperation with car manufacturer becomes stable, and the order degree rises; to the fourth quarter near the end of the year, the demand is smooth, and the order degree falls to 0.78, is lower than the previous quarter but still maintains at a high level. With the development of business and the continuous running of the car manufacturer, the supplier adjusts the level of self-service constantly and can achieve higher level of collaboration within the subsystem.

For demand subsystem, the order degree continued grows from 0.14 to 0.76 within a year. A linear growth appears in the first quarter to the third quarter, and the growth rate in the fourth quarter is slow down. The variation law is slightly different to the supply subsystem. With the cooperation from suppliers, the subsystem also reaches a high level of coordination inside.

From Fig. 5, we can see that the synergetic degree between two companies is not high, which up to 0.34 and even appears negative in the last quarter.

Although the order degrees of two subsystems in their respective enterprises are high, the degree of coordination between the two is low.

In the first three quarters, the order degrees of the two subsystems show an increasing trend, so the synergetic degree of S–DS also shows an upward trend. In the fourth quarter, the order degree of demand subsystem continues to rise, but the order degree of supply subsystem decreases, so that the synergetic degree of S–DS has a negative value.

It can be concluded that between the two co-enterprises, if there aren't real synergy, even though the order degrees within themselves are high, the two sides cannot achieve the purpose of win–win situation. That is, the improvement of synergetic level can't only rely on any one of the subsystems. It needs to master the evolution law of the whole system. In practice, enterprises should carry out production activities according to the law of the evolution of system, and strive to make the whole system to achieve the best synergetic state.

5 Conclusions

The coordination and competition mode in the automotive supply chain network system is an important synergetic mode. In the automotive supply chain, there is a need for an effective and stable partnership between car manufacturers and their vast supplier partners.

As the application areas of synergistic thought in the automotive industry continue to expand, car manufacturers and suppliers urgently need to find ways to establish an effective and stable partnership. Synergetics provides a way combining dynamics with random theory, which can reveal the evolution law of the relationship between AM–S, and give a measure to the synergetic effect.

Synergetics presents that only when the subsystems cooperate with each other, they can follow the self-organization evolution law and make the system to achieve synergy. In practice, a win–win partnership established by AM–S is the basis for coordination.

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