Analytic hierarchy process-based evaluation research on coal supply chain management collaborative system

In the dynamic market environment of economic globalization, the supply chain management (SCM) in Chinese coal industry is faced with serious problems such as lowered overall efficiency and yield rate, while the "horizontal integration" management to strength the supply chain management has obtained obvious advantages in the competition. Based on AHP, this paper analyses the network structure and collaborative network operation of 9 coal supply chains (SC), build the index system of coal supply chain management collaborative system (SCMCS), and makes dynamics simulation study for coal SCMCS by adopting the Vensim software. The results show that the index system of coal SCMCS is composed of three collaborative indexes in terms of strategy, business process and customer service, where the business process index is the core of index system. Also, the dynamics simulation modelling has been made for the system, to obtain the general level of CS, rebuild the sub-system flow chart and then promote the degree of order for the sub-systems in the adjusted plan.

Keywords: *Analytic hierarchy process (AHP), supply chain management (SCM), collaborative system (CS), dynamics simulation modelling.*

1. Introduction

As the economic globalization advances continuously, the fierce market competition has caused higher requirements for the market entity; the competition among the market entities is not only that among the enterprises, but that between supply chains [1-2]. The SCM, as one new strategic management system and development mode, gradually became the main means for enhancing the competitive advantages and reducing operation costs of different industrial enterprises [3]. The core of SCM is for promoting the overall efficiency and performance, and establishing long-term cooperative relationship with the clients, so as to effectively integrate the internal and external valid resources, optimize the overall efficiency and performance, and serve the whole market and the clients [4-5]. There exists violent competitions between the supply chains, so it is important to build one complete supply chain by mutual coordination and cooperation, aiming to realize the revenue maximization [6-7].

The synergetics theory provides one new-type management mode for the sound development of the overall supply chain by realizing the information system transferring and sharing between the enterprises, data transmission, and better collaboration between the different entities in the supply chain to meet the market demands and changes [8]. The enterprises at home and abroad has fully realized the importance of synergetics theory in SCM, and in the supply chain management mode, they can better respond to the global financial storms such as financial crisis etc. e.g. the famous enterprises, Apple, Dell and Wal-mart etc., all have achieved great success by the supply chain management mode [9-10]. With the coal industry at the transformation period in our country, its development has its own particularity, and the collaborative management of supply chain can better realize the coal information sharing, but the coal supply chain has certain difference from the other supply chains, therefore, it is necessary to build the evaluation system for the collaborative degree of coal SCM[11]. Based on AHP, this paper analyses the network structure and collaborative network operation of coal supply chains, build the index system of coal SCMCS, and finally makes dynamics simulation study to verify the system performance, providing the theoretical basis for realizing the coal information sharing, efficiency and performance maximization in future.

2. Collaborative network structure of coal supply chain

2.1 Analysis for coal supply chain network structure

The supply chain is generally composed of the supplier, manufacturer, distributor, retailer, and consumer, who, centred around the market changes, make outward delivery in the form of purchase orders [12]. Normally, the actual sales volume in the SCM system has small fluctuations, but its sales volatility has increased obviously. Fig.1 shows the details of SCM, including the planning, organization, coordination and control of all enterprises in the supply chain, and the overall planning for logistics, capital flow and information flow. The SCM collaboration includes three aspects in terms of organization,

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business process and information. Fig.2 shows the coal supply chain, including mine, processing enterprises, coal transportation enterprises and clients involved with the coal production, processing and sales, and also such enterprises of power, construction materials, metallurgy and chemical engineering, etc.

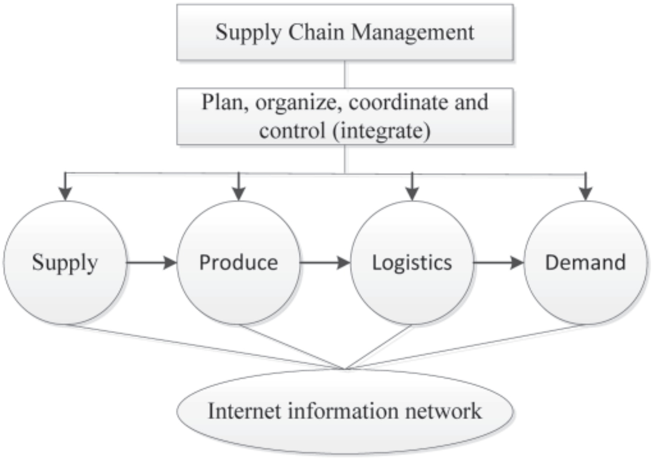

Fig.1 Supply chain management

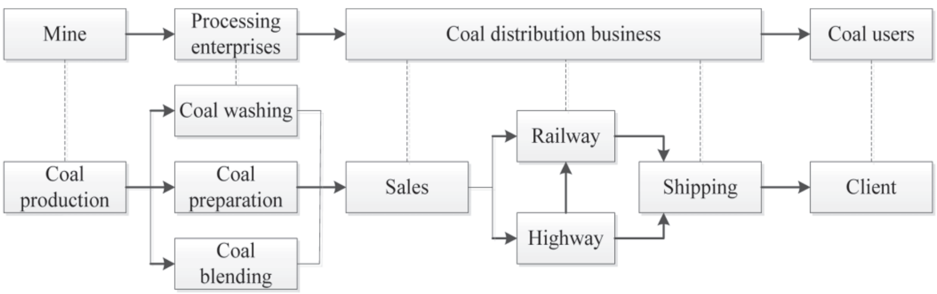

Fig.2 System interface of coal supply chain

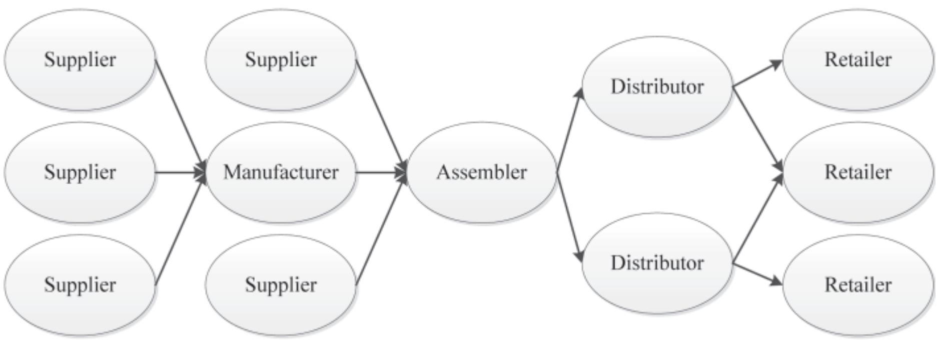

Fig.3 Supply chain network structure model

The coal SCM is the multi-enterprise collaborative system of vertical correlation and horizontal cooperation, persisting the principles of strategy, dynamics, innovativeness, cleanliness, harmonization, and integrated optimization etc. [13-14]. Fig.3 depicts the structural model of coal supply chain network, with the supplier, manufacturer, assembler, distributor and retailer, where the assembler is the key enterprise in the supply chain, having influence on the operation state of supply chain, effectively organizing and coordinating the logistics and capital flow in the supply chain.

2.2 Operation analysis of coal supply chain collaborative network

In the supply chain operation process, with various enterprise systems, cultures and targets, the enterprise shall ignore the operation of its following enterprise in the supply chain, which may cause the lower operation efficiency of the whole supply chain; therefore, one effective SCM is very important for the rapid and high-efficient operation of the whole supply chain, i.e. the collaborations in such aspects as supply, production, demands and capital flow of the whole supply chain are required [15]. Fig.4 depicts the collaborative operation of coal supply chain network: all enterprises in the supply chain are partners, focusing on cost, quality and service, but also have dynamic competitive relationship, causing the drift of core enterprises in the competition and thereby generating new supply chain of stable core enterprises; these enterprises make competition by price fluctuations which are influenced by such factors as clients, environment, competitors and core enterprises etc. [16-17].

3. Coal supply chain management collaborative system (SCMCS) evaluation

3.1 Establishment of coal SCMCS index system

The establishment of coal SCMCS was based on WEB information sharing service platform, and the communication protocol between the enterprises was also realized on this platform; besides, this platform includes the information of supply, production, sales, stock, logistics and client etc. Table 1 lists the chains of 9 coal supply chain (SC) networks; by analysis of the three indexes (degree of order for sub-system coordination and matching, collaborative capacity of supply chain information and collaborative degree of supply chain information of the 9 supply chains, the value of collaborative degree for the 9-coal supply chain management is finally obtained as shown in Fig.5.

By fully analysing the benefit of SC all node information collaboration for the node enterprise, the index system of coal SCMCS was established, also observing the principles of combining the macroscopic and microscopic, emphasis and

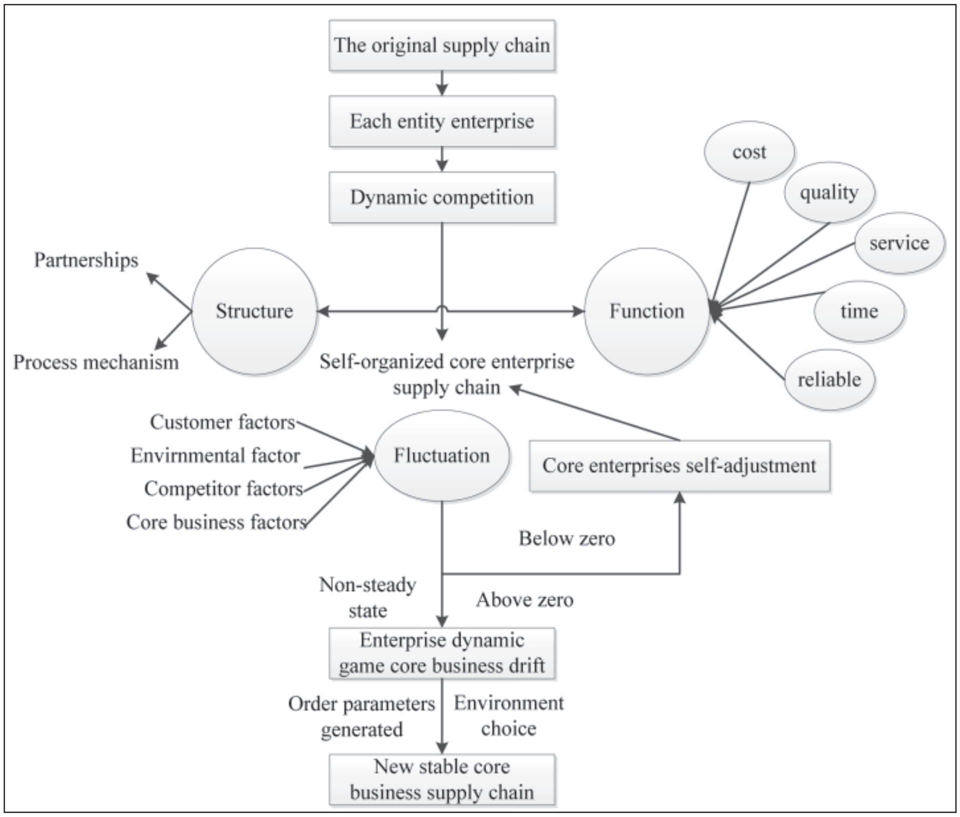

Fig.4 Coal supply chain network collaborative operation analysis

3.2 AHP-BASED COLLABORATIVE SYSTEM EVALUATION

Based on AHP method, this paper evaluates the coal supply chain collaborative system with coal transportation enterprise as the core, classifying the target of collaborative evaluation (A), the strategy collaborative system index B1, the business process index B2 and the customer service CS index B3 as Level 1 index, their internal group as Level 2, and the evaluation system as Level 3 as shown in Fig.6 in detail. The related literatures, determine the calculation value and standard value of every index, and then calculate the weight of every index system; Table 2 lists the relative-importance weight of A-B index, and Table 3 lists the calculated non-dimensional treatment value based on weight. In the same method, calculate the weight of

university, quantitative and quantitative method, and also the scientific principle, purpose principle and system principle. Fig.6 shows the index system of coal SCMCS, composed of three collaborative indexes in terms of strategy, business process and customer service, where the business process index is the core of index system; the business process index includes four sub-indexes in terms of planning, purchasing, production and transportation, with the purchasing collaborative index measured by the average purchasing cycle and average stock turnover, the production index measured by average on-time delivery rate, products process cycle and production/demand ratio, and the transportation index measured by the sales-output ratio.

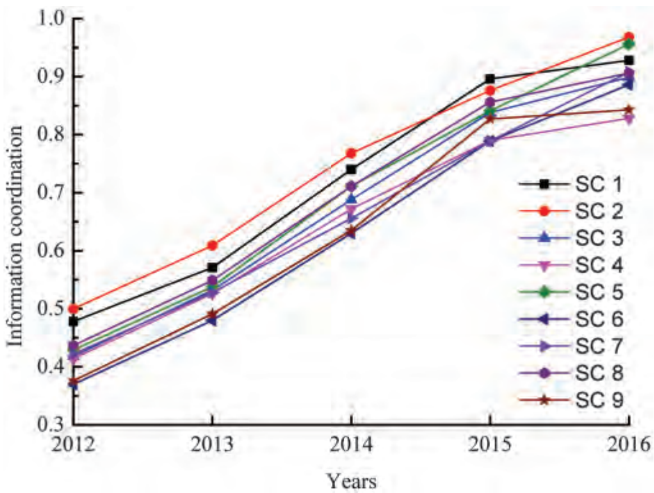

Fig.5 Coal supply chain information synergy

TABLE 1: CHAINS OF COAL SUPPLY CHAIN (SC) NETWORK

SC	Node composition
SC 1	Huangyan coal mine-Hengtai processing-Jinxi Xiyang marketing company-client 1
SC 2	Huangyan coal mine-Hengtai processing-Jinxi Xiyang marketing company-client 2
SC 3	Huangyan coal mine-Hengtai processing-Jinxi Xiyang marketing company-client 3
SC 4	Beiping coal industry-Hengtai processing-Jinxi Xiyang marketing company-client 1
SC 5	Beiping coal industry-Hengtai processing-Jinxi Xiyang marketing company-client 2
SC 6	Beiping coal industry-Hengtai processing-Jinxi Xiyang marketing company-client 3
SC 7	Dazhai coal industry-Yang processing-inxi Xiyang marketing company-client 1
SC 8	Dazhai coal industry-Yang processing-Jinxi Xiyang marketing company-client 2
SC 9	Dazhai coal industry-Yang processing-Jinxi Xiyang marketing company-client 3

Level 2 and Level 3 index, and also the scores of supplies chain collaborative system; plot the tendency chart of collaborative system in recent five years by Origin as shown in Fig.7, showing that it started to increase rapidly in 2013, and slowed down in 2015; besides it can also be found that the CS system of supply chain 2 is better to gain the maximum revenue.

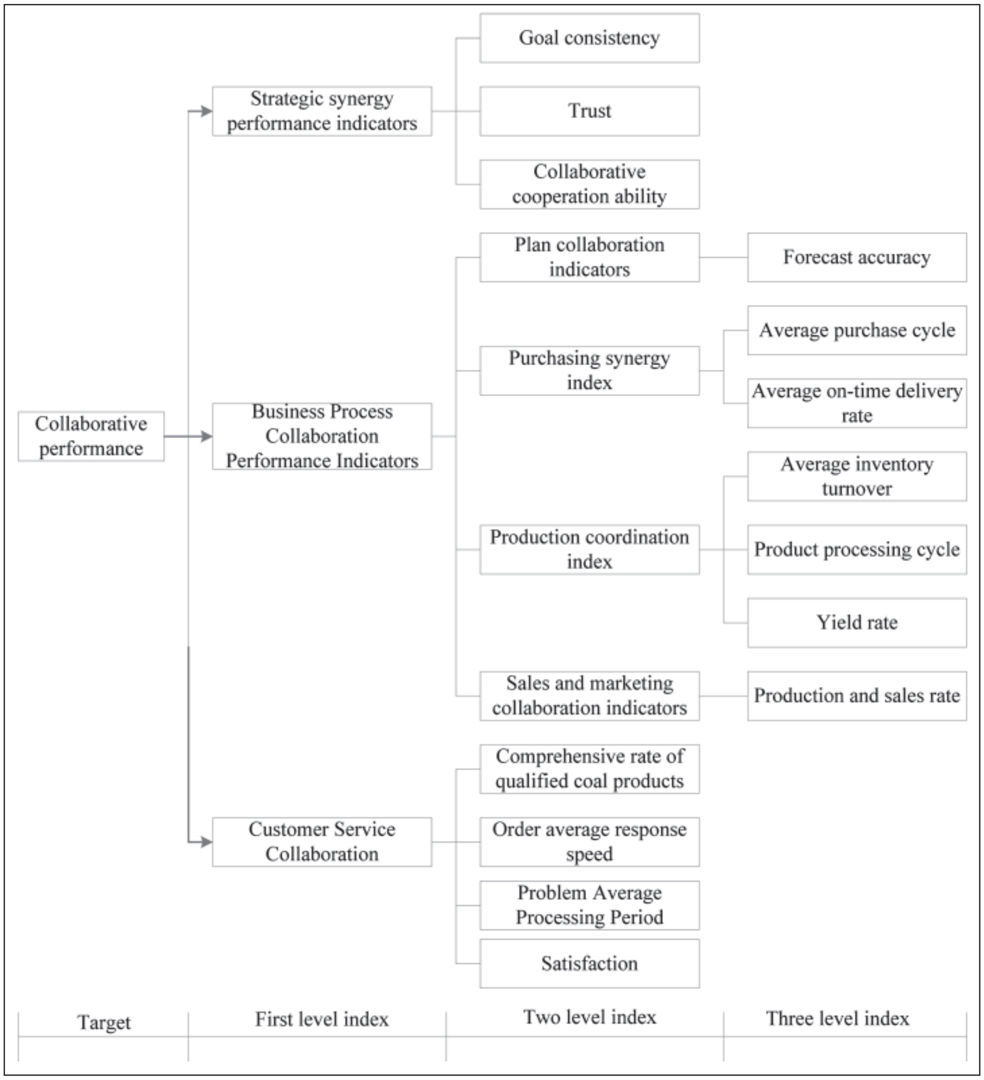

Fig.6 Coal supply chain collaborative performance index system

first was simulation study of actual scene, and the second was of simulated scene. The steps are as follows: firstly, define the condition, determining the parameters of labour, materials and financial resources etc. in the CS system; then based on the causal relationship build the system flow chart, and the causal-relationship diagram of SC system; finally, sub-divide the related influencing factors in the casual relationship system.

With Shanxi Coal Transportation and Sales Group Co., Ltd as the platform, covering different areas in the Group, city or county etc., and selecting the supply chain 2 above, the simulation modelling was established; Table 4 shows the 2012-2016 system collaborative degree and coordination performance value with its table function, and the degree of collaborative system is obtained as:

General level of CS = With lookup (Degree of collaborative ([(0,0)-(1,1)], (0.5, 0.625), (0.561, 0.694), (0.669, 0.791), (0.782, 0.893), (0.865,0.911))) ... (1)

4. Coal SCMCS dynamics simulation research

4.1 System dynamics simulation modelling

The coal SCMCS is characterized by dynamics and non-linearity; with complex relationship among the enterprises in the supply chain, it is very difficult to conduct study by static and local evaluation model, so, the system dynamics simulation is adopted. Among the four kinds of system dynamics software: Vensim, Goldsim, Powersim and Stella etc., the Vensim modelling software has been applied in this system dynamics simulation study. According to the established CS index system above, two plans were made, the

Table 2: A-B index relative-importance weight

A	B1	B2	B3
B1	0.5	0.31	0.42
B2	0.69	0.5	0.72
B3	0.58	0.28	0.5
Sum	1.77	1.09	1.64

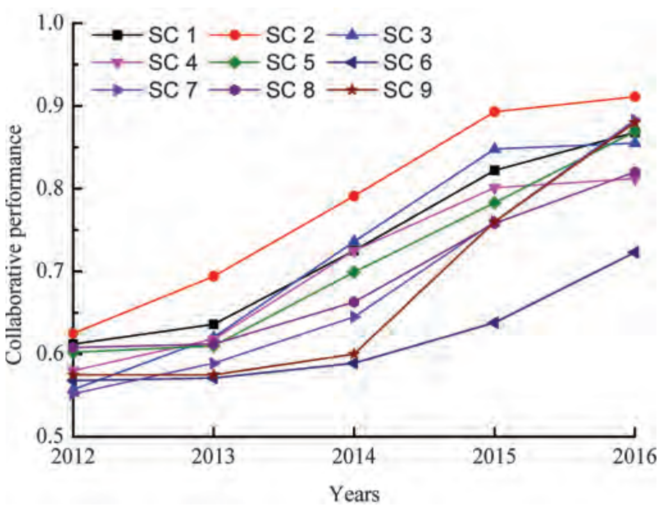

Fig.7 Supply chain collaborative performance trends

TABLE 3: A-B INDEX OF NON-DIMENSIONAL TREATMENT

A	B1	B2	B3
B1	0.282	0.284	0.256
B2	0.390	0.459	0.439
B3	0.328	0.257	0.305

TABLE 4: RELATIONSHIP BETWEEN THE DEGREE OF COORDINATION AND PERFORMANCE

Years	2012	2013	2014	2015	2016
Collaborative performance	0.625	0.694	0.791	0.893	0.911
Cooperation degree	0.5	0.561	0.669	0.782	0.865

4.2 SIMULATION ANALYSIS OF ACTUAL AND SIMULATED SCENES

The Vensim software has been adopted to make simulation analysis of actual scenes for the supply chain 2, with performance target value 0.9 and simulation time 20 quarters in the CS system. Fig.8 depicts the performance development trend in CS system, showing that in the 17th quarter, the target value 0.9 is reached, and afterwards the increase rate of curve is almost zero. Besides, take the sub-system of core enterprises as example, the Vensim software can output the analytic image of any influencing factor, hence, in this paper, the increment of order of degree in core enterprises is regarded as influencing factors, and its image is analysed as shown in Fig.9.

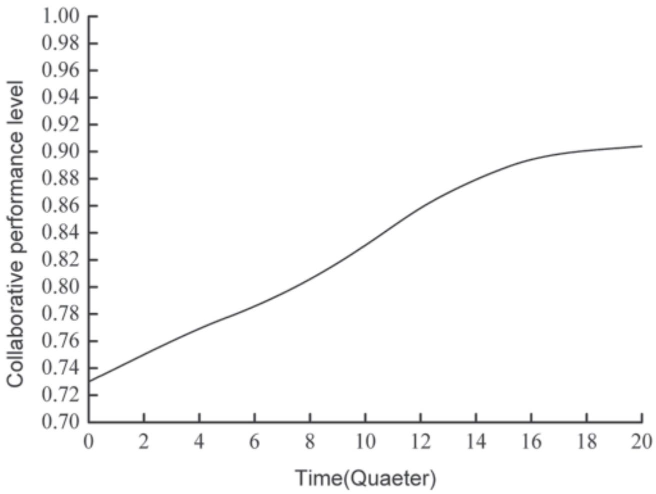

Fig.8 Collaborative performance level development trend chart

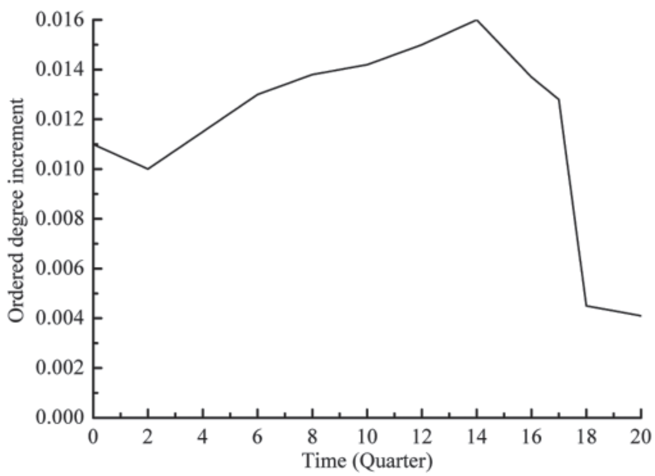

Fig.9 Increasing order of the core business

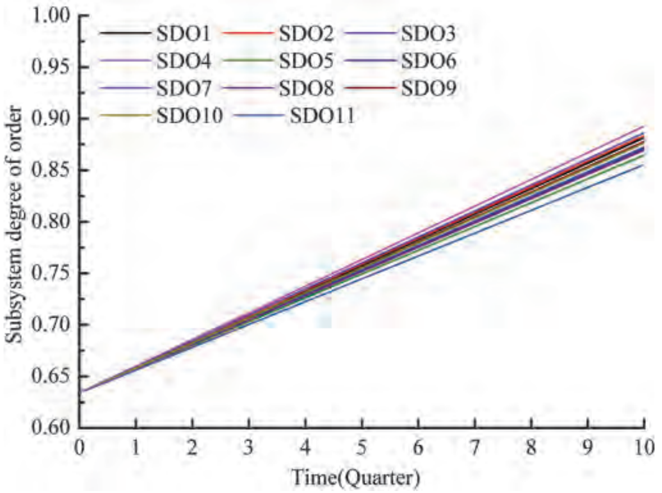

Fig.10 Various programs under the order degree of subsystems changes

The complex relationship among these influencing indexes in coal SCMCS system has impact on its sub-systems, and also causes mutual interaction between these indexes, therefore, only considering the weight of information collaborative factor cannot fully represent the effect of factor on the system. The four sub-systems of order of degree in coal supply chain were abstracted to one system of order of degree. Re-plot the sub-system flow chart, set the rate variable of original plan as 0.02, and add 0.02 successively in the following plan-adjustment. Fig.10 shows the simulation result of original plan and 11 adjusted plans, where CPD is collaborative performance level; compared to original plan, the order of degree of sub-systems in the adjusted plan has been all promoted.

5. Conclusions

Based on AHP, this paper evaluates the network structure and collaborative network operation of coal supply chain. The following conclusions are made:

(1) The coal SCM is the multi-enterprise collaborative system of vertical correlation and horizontal cooperation, persisting the principles of strategy, dynamics, innovativeness, cleanliness, harmonization, and integrated optimization etc.

(2) The index system of coal SCMCS is composed of three collaborative indexes in terms of strategy, business process and customer service, where the business process index is the core of index system.

(3) The Vensim is adopted to make simulation analysis of actual scenes for the supply chain 2, and the performance development trend diagram in CS system shows that in the 17th quarter, the target value 0.9 is reached, and afterwards the increase rate of curve is almost zero. Considering the mutual interaction between these system indexes, the order of degree of sub-systems in the adjusted plan has been all promoted.

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