RESEARCH ON KNOWLEDGE INNOVATION OF SUPPLY CHAIN ENTERPRISES FROM THE PERSPECTIVE OF THE THERMODYNAMIC ENTROPY THEORY

by

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The theory of thermodynamic entropy is applied for reference to solve the basic problems of supply chain management science and knowledge innovation of supply chain enterprises. As for entropy, only thermodynamic entropy, statistical physical entropy and information entropy have been recognized, so management entropy is defined as the generalization of entropy. According to the similarity between state change of management system and that of the thermodynamics system, the revelation of the microscopic mechanism of entropy essence by statistical physical entropy, and the foundation that information entropy is regarded as the generalization of entropy by scholars, it is concluded that management entropy exists and has the same properties as thermodynamic entropy. For instance, it becomes a measure of the degree of chaos and disorder of a system and the time vector of the management system. A knowledge innovation sharing model of supply chain enterprises is constructed based on the thermodynamic entropy theory, the process of knowledge sharing in supply chain is analyzed, and the possibility of knowledge sharing among supply chain enterprises from the point of view of game theory is discussed. The principal-agent theory is used to analyze the incentive strategy to promote knowledge sharing in supply chain, and the model of knowledge sharing in supply chain is established.

Key words*: internet of things, decision model, supply chain, management*

Introduction

In the development of thermodynamics, the concept of *entropy* was born. At first, the meaning of *entropy* refers to the degradation and depreciation of energy, which is used to describe the probability of the equilibrium state of the thermodynamic system, Dan *et al.* [1]. Entropy has a high or low level. High entropy means a high degree of chaos and disorder, and a low entropy means a high degree of centralized order, Wan *et al.* [2]. Since the concept of entropy came into being, people have applied its profound connotation interpret the related problems in the field of nature and humanities, and have exerted its beneficial theoretical guidance function, Mandal [3]. For example, by applying the *entropy* principle to medicine, it is recognized that the continuous absorption of negative entropy and the elimination of positive entropy are the basis for the maintenance of life. Another example is that, by applying the *entropy* principle to the ecological environment of the Earth, it is recognized that in order for the Earth to become a green home for mankind, humans must protect forests and green spaces that have access to

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negative entropy and reduce the emission of CO_2 and other gases that produce *positive entropy*, Wang and Chen [4]. In the same way, the *entropy principle* of thermodynamics can be applied to the exploration of knowledge innovation in supply chain enterprises. Especially in the current situation of the rapid development of electronic commerce, this kind of enlightenment will have more practical significance.

For any enterprise in the supply chain, the supply chain is a *knowledge source* with abundant knowledge resources. Knowledge sharing is helpful to promote knowledge innovation and improve the knowledge level and the overall competitive advantage of the supply chain. In this paper, the relationship among knowledge sharing, knowledge innovation and supply chain core competence is analyzed, and the principle of knowledge innovation in supply chain is analyzed by using the theory of entropy. Moreover, the negative entropy effect between knowledge entropy and knowledge is studied. The mathematical model of knowledge entropy and the model of knowledge innovation are constructed, and the strategies of knowledge innovation in supply chain are discussed. The purpose of this paper is to provide a theoretical reference for enterprises to conduct knowledge sharing practices and improve the overall competitive power of the supply chain.

The innovation of this paper lies in the analysis of the possibility of knowledge sharing among supply chain enterprises from the perspective of game theory, and the use of principal-agent theory to analyze the incentive strategy to promote knowledge sharing in supply chain. On this basis, the realization model of knowledge sharing in supply chain enterprises is established, which is helpful to apply the model directly to analyze and solve the competition problems of supply chain enterprises in real life. It also helps to provide guidance for managers in other industries.

Based on the theory of thermodynamic entropy, this paper studies the knowledge innovation of supply chain enterprises, which is based on the internet of things (IOT). The first part describes the current research situation. Then, the application of the decision model in enterprise supply chain management is analyzed. In the second part, the application of supply chain management in enterprises and the two-level decision model of enterprise supply chain commodity distribution are discussed. In the third part, the model proposed is applied to the distribution of retail enterprises.

Related work

Throughout the literature on knowledge innovation of supply chain enterprises at home and abroad, many scholars have carried out related research. Stentoft *et al.* [5]and other scholars believe that as knowledge increasingly becomes one of the key factors that constrain the overall operational efficiency of supply chain, the key content of knowledge management in supply chain is to strengthen the knowledge sharing and communication among members of supply chain and to improve the efficiency of knowledge innovation and application is its direct goal. At the same time, they also point out the main content of knowledge management in supply chain and provide the corresponding strategy. Heraud [6], consider that knowledge management is to improve the efficiency of knowledge innovation and application and make the knowledge level of supply chain members to achieve coordination and optimization. Chen *et al.* [7] believe that enterprises share and utilize the knowledge of upstream and downstream enterprises through knowledge-based supply chain cooperation, which makes the knowledge of each member enterprise in the supply chain continuously improve its value in the movement, so as to enhance the core competencies of the entire supply chain. Zhao *et al.* [8] think that the knowledge management problem in supply chain is very important for improving the core competitiveness of supply chain enterprises and the overall performance of supply chain. Rashid *et al.* [9], analyze the main factors that should be considered in the evaluation of knowledge management performance in supply chain, and establish an index system to evaluate the performance of knowledge management in supply chain from six perspectives, creation of customer value, ability to acquire knowledge, ability to share and disseminate knowledge, level of application of knowledge, level of knowledge stock and knowledge management platform. Cong *et al.* [10], use four steps of socialization, externalization, integration and internalization in the SECI model to analyze the process of knowledge transformation in supply chain. After analyzing the characteristics of knowledge management in supply chain, problems that should be paid attention in knowledge management in supply chain are put forward.

To sum up, the existing domestic and foreign researches on supply chain knowledge management and knowledge sharing mainly focus on its importance, content, principles, implementation framework and case analysis. The specific processes and methods of knowledge management and knowledge sharing among supply chain enterprises are not systematically studied. In this paper, applying the theory of thermodynamics, the relationship between knowledge sharing and knowledge innovation in supply chain is analyzed, and the process of knowledge innovation in supply chain based on knowledge sharing is studied. It is pointed out that the ultimate goal of knowledge sharing and knowledge innovation in supply chain is to improve the knowledge ability and synergistic ability of supply chain.

Application of thermodynamic theory decision-making model in enterprise supply chain management

Application of supply chain management enterprises

From the outside of the enterprise, first of all, the IOT technology helps to strengthen the relationship between enterprises and consumers. As shown in fig. 1, IOT technology can promote effective connectivity, improve customer service quality and customer loyalty, and make the enterprise enjoy the consumer information and preference, thus reducing the search cost of the business in the future. Secondly, superior IOT technology can help enterprises to enhance the strength and accuracy of marketing, increase the difference of products, improve the agility of enterprises, enhance the ability of enterprises to grasp the market opportunities, and then improve the performance of enterprises. Thirdly, superior IOT technology helps firms to strengthen the management and control of the whole supply chain and value chain, and strengthen the relationship between enterprises and suppliers. Although some studies show that the impact of the IOT technology on corporate performance is no longer significant. However, this paper holds that the influence and change of the IOT technology on the enterprise from the inside and outside of the enterprise is significant and cannot be ignored. Thus, consistent with the previous research, this paper thinks that the superior IOT technology of the enterprise can increase the profit for the enterprise, reduce costs, and then improve corporate performance.

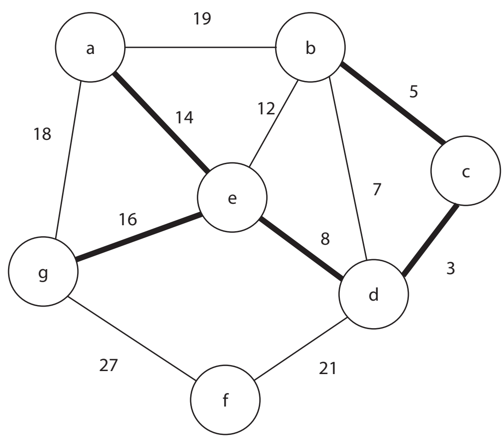

Figure 1. The IOT technology

This paper argues that the IOT technology can produce unique competitive advantages and intangible assets for enterprises, and market participants can capture this competitive advantage related to the IOT technology. Therefore, the IOT technology and enterprise value have a positive relationship. In a word, superior IOT technology improves the ability of response and prediction market changes, reduces the impact of unexpected events on organizational costs and benefits, and further reduces the volatility of enterprises. In addition, when the degree of environmental uncertainty in the industry is different, the demand for information processing is also different. When industry uncertainty is high, the changes in the operating environment of the enterprise will also be more drastic. Superior IOT technology can enable enterprises to better collect, process and disseminate information and knowledge, in order to generate timely and effective competition strategies. Products and processes can also be adjusted faster and more effectively to meet market demand. Superior IOT technology helps enterprises to make more reasonable decisions in uncertain environments, and reasonable decisions have a strong positive impact on enterprise performance in a highly dynamic environment. Therefore, the greater the uncertainty of the environment, the greater the impact of the IOT technology on corporate performance is. In addition, the competitive advantage of the superior IOT technology is not only reflected in the improvement of enterprise performance which is likely to be captured by the market but also ultimately reflected in the value of the firm.

Two-level decision-making model of commodity distribution in enterprise supply chain

After the emergency, the chain retail enterprises must allocate enough goods to each store quickly. At this time, the time benefit is much more important than the economic benefit. In the emergency deployment process of chain retail enterprises, the biggest goal is to reduce the time cost of emergency dispatch, while at the same time, because the goods of temporary transit point often cannot meet the needs of all stores at the same time, it is necessary to ensure that temporarily insufficient goods can be deployed to stores as reasonably as possible. This paper will build a two-level programming model of commodity scheduling according to the two objectives that the chain retail enterprises' emergency dispatch time is the shortest, and the overall satisfaction of each store is the highest. The chain retail supply chain with more rescue points and emergency points is shown in fig. 2.

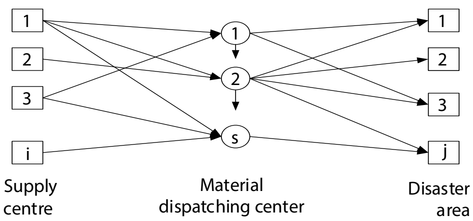

Figure 2. Map of emergency supply and distribution system with multiple outlets and multiple emergency points in chain retail supply chain

In this paper, for the convenience of constructing the model, the following five assumptions are developed:

Hypothesis 1: The chain retail supply chain scheduling center knows the distance between all the commodity reserve points and the stores, and their positions are fixed. The type and quantity of goods contained in the reserve point are known. After the disaster, the transportation factors and the damage of infrastructure are not considered, and only the shortest distance distribution scheme is considered.

Hypothesis 2: After an emergency, the communication between the decision department and the stores is normal. The previous forecast for commodity demand is also reasonable.

Hypothesis 3: All distribution vehicles' capacity is in good condition, and the traffic from the initial position the reserve point is good and the infrastructure works normally.

Hypothesis 4: The goods required by the deployed stores do not contain frozen goods.

Hypothesis 5: There will be no commodity exchange between temporary transit points.

$$\min f_1 = \sum_{\forall i}\sum_{\forall s}\sum_{\forall k} z_{is}\left(\frac{T_{is}}{x_{is}^k + t_s}\right) + \sum_{\forall s}\sum_{\forall j}\sum_{\forall k} z_{sj}\left(\frac{T_{sj}}{x_{sj}^k c_j + t_j}\right) \tag{1}$$

$$S.t. \quad s_i^k(t) = \delta_i^k(t) + \left[\alpha_i^k(t-1) - \sum_{\forall s} x_{is}^k(t-1)\right] \tag{2}$$

$$R_s^k(t) = \sigma_s^k(t) + \left[R_s^k(t-1) - \sum_{\forall s} x_{is}^k(t-1)\right] \tag{3}$$

$$x_{is}^k(t) \le R_s^k(t) \tag{4}$$

$$\sum_{\forall i}\sum_{\forall s} x_{is}^k(t) \le \sum_{\forall i} \alpha_i^k(t) \tag{5}$$

$$\sum_{\forall i}\sum_{\forall s} x_{is}^k(t) \le \sum_{\forall s} R_s^k(t) \tag{6}$$

$$x_{is}^k(t) \ge 0 \tag{7}$$

In order to minimize the time taken for a chain retail enterprise to dispatch its goods to a store, it is necessary to reduce the distance and frequency of distribution, so:

- equation (1) aims to minimize the transportation time cost from the supply point to the commodity transfer center and that from the commodity dispatching center to the chain retail store,
- equation (2) refers to the total quantity of commodities, k, that can be provided by supply point, i, at each time, that is, the sum of the quantity of newly added commodities, k, of the current period and that of surplus goods of the previous period,
- equation (3) means that when time is, t, the demand for commodity turning center, s, for commodity, k, is the total amount of new demand in the current period and unsatisfied quantity of commodity, k, in the last period,
- equation (4) means that at the time, t, the quantity of commodity, k, assigned by supply point, i, to the commodity turning center should not exceed the demand for the commodity, k, of the commodity turning center s,
- equation (5) means that at time, t, the number of commodities allocated by the supply point should not exceed the quantity of the goods stored at the supply point at that time,
- equation (6) means that at time, t, the number of goods in the commodity turning center is less than the demand of the store, and
- equation (7) means that the number of goods obtained by all the transition centers is all greater than or equal to 0.

Lower-level distribution optimization model. The number of commodities to be obtained by the store should be met as far as possible:

$$\min f_2 = \sum_{\forall j}\sum_{\forall k} \frac{R_j^k}{c_j \sum_{\forall s} z_{sj} x_{sj}^k} \tag{8}$$

$$S.t. \quad \alpha_s^k(t) = \delta_s^k(t) + \left[\alpha_s^k(t-1) - \sum_{\forall j} x_{ij}^k(t-1)\right] \tag{9}$$

$$R_j^k(t) = \sigma_j^k(t) + \left[R_j^k(t-1) - \sum_{\forall j} x_{ij}^k(t-1) \right] \tag{10}$$

$$\sum_{\forall j}\sum_{\forall s} x_{sj}^k(t) \le \sum_{\forall s} \alpha_s^k(t) \tag{11}$$

$$\sum_{\forall j}\sum_{\forall s} x_{sj}^k(t) \le \sum_{\forall s} R_s^k(t) \tag{12}$$

$$\sum_{\forall s} x_{sj}^k(t) \le R_j^k(t) \tag{13}$$

$$\sum_{\forall s} x_{sj}^k(t) \ge \eta_k R_j^k(t) \tag{14}$$

$$x_{sj}^k(t) \ge 0 \tag{15}$$

– equation (8) means to take the minimum value of the cost of the unsatisfied need for relief goods,
– equation (9) means that the quantity of commodity, k, that can be provided by the commodity transition center s at each time, t, is the sum of the quantity of the newly added commodity, k, in the current period and the quantity of the surplus commodity, k, of the previous period,
– equation (10) means that the store J's demand for commodity, k, is the total amount of the new demand for the current commodity, k, and the unsatisfied quantity of the previous commodity, k, when the time is t,
– equation (11) means that the quantity of goods allocated by the commodity turning center is less than or equal to its storage capacity,
– equation (12) means that the number of commodities supplied by the transition center is less than or equal to that of commodity demand in the transition center,
– equation (13) means that the commodity turning center supplies commodities to the store; the total amount of commodity, k, is less than or equal to the number of store J's demand for i,
– equation (14) refers to how to make the scheduling results most effective; because of the frequent occurrence of stores with excessive demand for goods, other stores cannot get effective supply, which leads to unreasonable allocation; if the store is preset with a minimum satisfaction rate, the number of goods available to a store must not be less than the minimum value, and
– equation (15) means that the number of commodities supplied by the commodity transition center, s, to store, j, is greater than or equal to zero.

Experimental design and analysis

At present, as a whole, the construction of emergency logistics distribution center related to chain retail supply chain in China is not mature. Considering the actual situation, this paper assumes that each candidate emergency logistics distribution center has been established under the unexpected events. All kinds of emergency goods needed in the disaster area are from the emergency logistics distribution center to the transportation the emergency demand point, and the emergency logistics distribution center has sufficient resources.

There is an emergency somewhere. The demand of each store in a chain retail supply chain is calculated by the forecasting algorithm of commodity demand in chain retail supply chain based on neighborhood rough set and GA-SVM. There are fifteen retail stores in the retail sector.

The location and delay time of each store are shown in tab. 1, and the demand for goods is shown in tab. 2. The chain retail supply chain now needs to work out a distribution plan, that is, to determine x_{ij}^k and x_{sj}^k ($i = 1, s = 1, 2, j = 1, 2, 3,\ldots, 8, k = 1, 2, 3$). Hence, it can make the emergency time shortest and the total quantity of emergency distribution close to the preferred demand.

Table 1. Data of disaster hit stores

Store number	X-co-ordinates	Y-co-ordinates	Unit delay time
0	180	90	1.45
1	100	85	1.26
2	245	70	1.62
3	190	55	1.75
4	235	220	1.81
5	300	255	1.34
6	80	80	3.52
7	45	125	1.57
8	260	120	2.35
9	135	136	1.41
10	40	165	1.39
11	125	230	1.15
12	190	290	0.68
13	210	45	2.16

Table 2. Commodity demand data for disaster hit stores

Store number	Commodity 1	Commodity 2	Commodity 3
0	41	2	20
1	30	7	13
2	11	9	16
3	33	2	18
4	8	5	18
5	40	3	13
6	13	4	35
7	37	4	16
8	61	8	24
9	21	3	14
10	46	7	14
11	53	6	12
12	51	7	7
13	59	5	22

Parameters involved in the algorithm include: population size $A = 100$, iteration number = 120, crossover rate $P_j = 0.9$, rate of variation $P_b = 0.01$. Without optimization, the time cost is 60 units and the cost of unsatisfied demand for relief goods is 8 units, which are all higher than the cost during optimization. It is proved that the model of supply chain commodity distribution two-level programming model and the collaborative decision making algorithm of supply chain commodity distribution are effective. This paper first expounds the basic principle, characteristics and superiority of cuckoo algorithm and genetic algorithm, and then puts forward a two-level programming algorithm based on the cuckoo algorithm-genetic algorithm, which produces a collaborative decision-making algorithm for commodity distribution in chain retail supply chain. The genetic algorithm and the cuckoo search algorithm for integer programming are designed, and the steps for solving the two-level programming model of commodity distribution are discussed in detail. Based on the MATLAB7.5 simulation platform, the feasibility and effectiveness of the collaborative decision algorithm for commodity distribution in the chain retail supply chain for solving the commodity scheduling problem in the event of an emergency are verified by examples. In this paper, the attribute reduction algorithm of commodity demand sample based on neighborhood rough set is used to reduce the influencing factors of commodity demand prediction in chain retail supply chain. There are 19 original attribute data in the sample data set of the influencing factors of commodity demand prediction in chain retail supply chain. After the reduction of neighborhood rough set algorithm, 8 key attribute data are left. In this paper, the index of influencing factors changes rapidly when the emergency occurs. In this paper, according to the index data stream of the influencing factors of the chain retail supply chain commodity demand prediction, the dynamic demand forecasting algorithm based on neighborhood rough set and GA-SVM is used to predict the dynamic demand of store merchandise. The 3-D graph of the optimization selection result of GA-SVM parameters is shown in figs. 3 and 4.

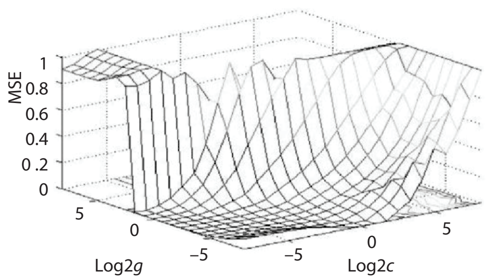

Figure 3. The GA-SVM parameter optimization and selection results (B_{estc} = 0.57435, g = 9.1896, CV_{mse} = 0.09284)

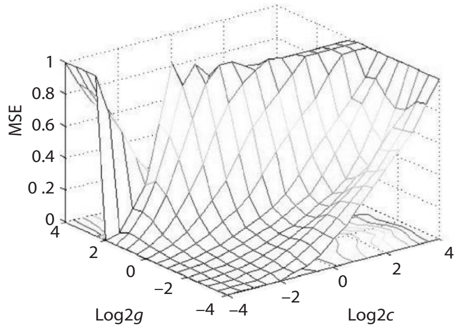

Figure 4. GA-SVM parameter optimization and selection results (B_{estc} = 0.5, g = 8, CV_{mse} = 0.090953)

Store distribution is characterized by a small amount of distribution and high distribution frequency. Based on the data flow of the influencing factors of the chain retail supply chain commodity demand prediction, this paper uses the neighborhood rough set and GA-SVM algorithm to forecast the store merchandise's dynamic demand and compares it with the original demand data. The simulation results of commodity demand forecasting error show that the demand forecasting algorithm based on neighborhood rough set and GA-SVM is used to predict the commodity demand in chain retail supply chain, and the prediction accuracy is very high. The maximum error is 5.71%, the minimum error is 0.60% and the average error is 2.84.

Conclusion

The study of supply chain knowledge management is a very complicated problem. With the deepening of China's integration into the world economy and the increasing international competition, the study of supply chain knowledge management is particularly important. Based on the theory of knowledge flow, this paper analyzes the types and levels of knowledge in supply chain and the model of knowledge flow among enterprises in supply chain. Moreover, it determines that the motivation of knowledge sharing in supply chain is to improve the return on knowledge investment, enhance the ability of enterprise market preemption, realize the integration and optimization of knowledge resources, and enhance the competitiveness of supply chain. Also, the goal of each stage of the knowledge sharing process in supply chain is discussed. The knowledge innovation of supply chain based on knowledge sharing is analyzed, and the relationship between knowledge sharing and knowledge innovation is explored. It is found that knowledge sharing initiates, promotes, tests and corrects knowledge innovation. In this paper, the principle of knowledge innovation in supply chain is analyzed by means of the theory of entropy, and knowledge entropy is put forward. Moreover, the negative entropy effect is analyzed, and the model of knowledge innovation based on the theory of entropy is established. Knowledge sharing and innovation in supply chain is a very practical research subject, and it is also a management method which needs heavy investment in the early stage and is difficult to be effective in the short term. Therefore, the research on it must be comprehensive, accurate and careful. This paper should carry out follow-up empirical research on the basis of the previous theoretical research. Through supply chain enterprise research and data collection, theoretical research is supplemented. Because of the restriction factors such as the length of papers, data collection, enterprise research, especially the structure of personal knowledge and the limited research level, there are inevitably many defects in this paper, such as insufficient empirical research. This will also become the driving force of my further efforts.

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