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FOOD COLD CHAIN ROUGH SET MODEL BASED ON GRAY SIMILAR CORRELATION RELATION AND ITS APPLICATION

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ABSTRACT

This study makes a deep systematic analysis on food cold chain logistics operative system. Firstly, gray correlation analysis is used to determine key input index that has important influence on system output. Then based on gray correlation cluster analysis, absolute relational degree between indexes was calculated using gray modeling software and index correlation matrix is established. Cluster results are obtained according to determination of correlation degree and critical value. Key sequential parameters of system in operating state are confirmed. Comprehensive operating state of system is evaluated using constructive method based gray rough set model and combining with gray system theory and rough set methodology. At last, uncertain problem such as difficulty in processing gray based on one methodology is solved in an innovative way.

1.Introduction

In recent years, food safety accidents such as bad edible oil, Sudan red and melamine-tainted formula milk powder severely threatens health of people (Powell et al., 2014). A series of food safety issues make people think about the reason for such a situation. It is urgent to figure out how to solve or improve food safety problem. As one of China's traditional industry, the development of food industry is very rapid (Barbara et al., 2010). Safety, freshness and variety are the foundation that ensure value of food and create added value, especially for perishable food. In trans-regional or global supply chain which circulates food with high value, how to normalize cooperative operation and monitor management in a scientific way is concerned by both basic staff and managers in the whole network chain. Safety and freshness are also the bottleneck for ensuring quality of fresh and perishable food. Rough set theory and gray system theory are proposed aiming at processing different types of uncertain problems. Though they have different basis and analyze and process uncertain problems in different perspectives, there is intersection between their research fields, i.e., theory, research method and means of them has something in common. If they can learn from each other to make up their own weakness, uncertain information can acquire more effective processing. Research on food cold chain logistics cooperative system has great theoretical and practical meaning. Based on a deep analysis on food cold chain logistics cooperative system, this study first constructs a parameter system for food cold chain logistics system, calculates index which dominates the operation of food cold chain logistics system and finally, evaluates cooperative operation state of food cold chain logistics system.

2. Materials and methods

2.1. Food cold chain logistics cooperative system and theoretical basis

Cold chain is used for describing a series of correlated operation such as production, delivery, storage and resale of refrigerated and frozen food (Zou et al., 2013). Logistics optimizes goods or service production network through predicting need and demand of customers and acquiring necessary capital, material capital, staff, technology and information, thus to create space utility, time utility and quality utility of logistics activities (Soysal, 2014). Rough set theory, proposed in 1980s, is a soft calculation method used for processing uncertain problems. Its largest advantage is that, apriori information except data set is not needed. It is suitable for discovering potential knowledge in data and can provide a complete set of method for simplification of information system and extraction of decision table rule (Subrat et al., 2013). Gray system theory believes that, whether system would appear problem of incomplete information depends on levels of recognition, information and decision. Uncertain quantity of low-level system is the certain quantity of high-level system. Rule of system can be revealed making full use of known information (Wang et al., 2014). The main body of food cold chain logistics system includes member enterprises on refrigeration network chain, raw material suppliers, food producer and processer, food dealer and wholesaler and food cold chain logistics service supplier (Wang et al., 2015). Structure of food cold chain logistics system differs greatly in practical economical operation, and there is no absolutely specified excellent structure. An adaptive structure is quite important for supply chain logistics system with different characteristics. Based on the above analysis on components of food cold chain logistics system, we make a division on category of structure in terms of constituent type of main body and scale of main body. Main body of food cold chain logistics system can be divided as follows according to different type of main body (Table 1):

Table 1. Structure category division based on type of main body

Structure category	Main body of logistics operation
Direct selling type	Supplier or producer-retailer
Complex type	Supplier-producer-retailer
Logistics enterprise in service type	The third party logistics enterprise provide logistics service
Logistics business in self support type	Enterprise engaging in production and processing or retailing and wholesale

Food cold chain logistics system has different scale. Scale of system is represented by number and scale of main body and equipment. Based on that, structure of food cold chain logistics system can be roughly divided as shown in Table 2.

Table 2. Structure division based on number and sale of main body and equipment

Structure category	Number and scale of main body	Object	Equipment needed
Convergence (T type)	Small amount but large scale of supplier and clients	Processing/selling foods	Large scale
Symmetry (H type)	Large amount but small scale of supplier of supplier; clients on the opposite	Food whose production place and consumption place is far away	Large-scale vehicle and small-scale refrigeration house

Divergence (A type)	Small amount of suppliers and large scale of supplier; clients on the opposite	Food with concentrated production place and dispersed selling place	Small-scale vehicle and large-scale refrigerator house

Customer is the end of food cold chain logistics system. It aims to provide satisfactory foods for customer realize maximum profit of member enterprises and reflect efficacy of food value chain. Food cold chain logistics system which is different from ordinary systems is characterized by high safety, irreversible quality, high sensitivity to environment, high cost, complex technology and highly uncertainty of information.

3. Results and discussions

3.1. Analysis of food cold chain logistics system cooperative model

3.1.1. Construction of state parameter of food cold chain logistics system

Based on dynamic systematic theory, state variables is a group of systematic parameters determining systematic behavioral characteristics (Christopher et al., 2013). Construction of state parameter system differs due to different selection of method and evaluator, but the basic principle following in construction of state parameter system is consistent (Francis et al., 2014). First, state parameter selected should be key variable which can describe system state; second, state parameter system constructed should be completed. Thirdly, state parameter selected should be distinguished according to role of member enterprises. Fourth, availability and accuracy of state parameter should be ensured.

State parameter system constructed based on qualitative analysis differs. This study constructs food cold chain logistics system state parameter based on pattern of input, conversion and output and dynamic systematic theory. According to the analysis on connotation of food cold chain logistics system in this study, systematic input state parameter system can be divided into main body, object, equipment and information. System switching is food cold chain logistics system cooperative process. System output is the objective which should be achieved by food cold chain logistics system coordination. System output state parameter system can be divided based on food safety, logistics operating efficacy, logistics cost and satisfaction of client.

3.1.2. Analysis of key index of food cold chain logistics cooperative system

In the process of system coordination, there would be few state parameters which completely dominate macroscopic behavior and ordering degree of system. This kind of state parameter is order parameter. Order parameter occupies a leading position in the cooperative behavioral process of system and also dominates other state parameter as well as order condition and changes of degree of order of subsystem (Forrest et al., 2008). When order parameter and slaving principle are used in food cold chain logistics system coordination system, the core idea lies on find out the index that plays a leading domination effect in system coordination among a large amount of parameters influencing food cold chain logistics state.

Gray correlation analysis is used to analyze the important degree of all input elements output by system. Procedures for calculation of gray correlation degree are as follows (Wang et al., 2011).

Suppose $R_0 = \left(r_0(1), r_0(2), r_0(3), \ldots, r_0(n)\right)$ as sequence group of systematic characteristic behavior and

$$R_1 = \left(r_1(1), r_1(2), \ldots, r_1(n)\right) \ldots R_i = \left(r_i(1), r_i(2), \ldots, r_i(n)\right)$$

as relevant behavioral sequence. In the system, there are two any irrelevant behavioral sequences.

(1) Solution of initial value image

$$R_i = \frac{r_i}{r_i(1)} = \left(r_i(1), r_i(2), \ldots, r_i(n)\right), i = 0,1,2,\ldots m$$

(2) Difference sequence

$$\Delta_i(k) = \left|r_0(k) - r_i(k)\right|, \Delta_i = (\Delta_i(1), \Delta_i(2), \ldots, \Delta_i(n)), i = 1,2,\ldots,m$$

(3) Solution of maximum difference and minimum difference

(4) Solution of correlation coefficient

$$\gamma\left(r_0(k), r_i(k)\right) = \frac{\min\limits_i \min\limits_k \left|r_0(k) - ri(k)\right| + \zeta \max\limits_i \max\limits_k \left|r_0(r_0(k) - r_i(k))\right|}{\left|r_0(k) - r_i(k)\right| + \zeta \max\limits_i \max\limits_k \left|r_0(k) - r_i(k)\right|}$$

(5) Calculation of correlation degree

$$\gamma(r_0, r_i) = \frac{1}{n}\sum_{k=1}^{n} \gamma(r_0(k), r_i(k))$$

Thus according to comprehensive correlation degree between system input element index and output element index, we can determine which system input element plays important domination effect in objective of food cold chain logistics system coordination.

Evaluation and observation of food cold chain logistics cooperative system can be represented by a large number of state parameters. But in practice, some indexes are correlated and mixed. We consider dividing observation index into different categories, screening and deleting to simplify evaluation process or assessment standard on the condition that ensure basic correct evaluation and decision. Gray cluster is a method that divides observation indexes or evaluation objects which are mixed through gray correlation matrix or white function of gray number into several definable categories. Through gray correlation cluster analysis, we can determine cluster of index, thus to further confirm operation state of representation element representation system and avoid loss of information (Liu et al., 2012). The following procedures for gray correlation cluster analysis are shown in Figure 1.

(6) Establish index correlation matrix and calculate absolute correlation degree

	r_1	r_2	……	r_n
r_1	ε_{11}	ε_{12}	……	ε_{1n}
r_2	ε_{21}	ε_{22}	……	ε_{2n}
……			……	
r_n	ε_{n1}	ε_{n2}	……	ε_{nn}

Figure 1. Procedures of gray correlation cluster analysis

(7) Cluster results can be obtained by making critical value r determination on ε_{ij} (0≤r ε_{ij} ≤1). The division is more detailed if r is closer to 1.

Through the above procedure, key index system which can represent food cold chain logistics cooperative system operating state can be obtained.

3.1.3. Food cold chain logistics cooperative system state evaluation

Typical rough set theory and method had been successfully applied for processing imprecise, inconsistent and uncertain data and knowledge and calculating order parameter with attribute reduction. But it cannot be applied for evaluating overall operating state of system (Gong et al., 2006). The most important thing is that, typical rough set theory has an assumed premise, i.e., all available individual objects can all be given complete description by attribute set. That means, when $C = \{r_1, r_2, \ldots, r_n\}$ stands for definite set of individual objects and $Y = \{y_1, y_2, \ldots, y_m\}$ stands for attribute set, then for any y from Y, r from C, attribute value y(r) exists and is confirmed.

Though the food cold chain logistics coordination system researched in this study focuses on coordination of different elements, it is still a complex and highly uncertain system which is imperfect in acquiring information. Therefore, introducing gray system theory and rough set theory into innovative research of food cold chain logistics cooperative system is quite necessary. Table 3 shows the difference and correlation between rough set theory and gray system theory.

Table 3. Difference and correlation between rough set theory and gray system theory

	Rough set theory	**Gray system theory**
Similarity	Any apriori information except data requiring processing is needed.	
Difference	A large amount of data can be simplified.	Few data, poor information and little information much information
Correlation	Gray system theory makes up the limitation of rough set theory, i.e., only capable of processing strict equivalence relation and discover uncertain data or knowledge and rules implied in information.	

3.2. Empirical analysis of food cold chain logistics system cooperative model

The reason to make empirical analysis on food cold chain logistics system cooperative model is to prove the scientificity and practical meaning of state parameter system construction, key index calculation analysis and overall operation state evaluation model.

3.2.1. Empirical analysis for state parameter system of food cold chain logistics system

The empirical object is directing selling-type food cold chain logistics system, i.e., the third party cold chain logistics enterprise X provides logistics service. Main body involved includes food producer and processer, food wholesaler and retailer and cold chain logistics enterprise X, as shown in Figure 2.

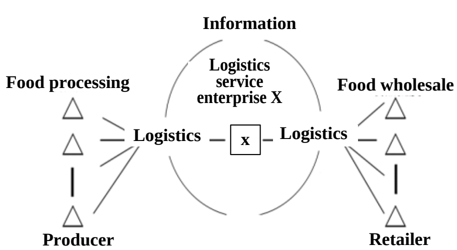

Figure 2. Structure of the food cold chain logistics system for empirical analysis

In this study, the purpose of confirming food cold chain logistics cooperative system operation is to ensure safety, improve logistics efficiency; decrease logistics cost and enhance client satisfaction.

3.2.2. Key index and state evaluation and calculation of empirical food cold chain logistics system

Input index and output index in food cold chain logistics system state parameter system is distinguished and gray correlation analysis is used to identify key elements that plays key role in system output. Degree of comprehensive correlation between input index and output index is shown in Table 4. According to gray correlation calculation result and research results obtained by other people, we can draw the conclusion that, input index that plays key influence on safety of logistics include quality of logistics staff, number of refrigeration vehicle, investment amount of information system and utilization rate of refrigeration house area. Input index that has key influence on cost of logistics include total value of circulated food, number of refrigeration vehicle, utilization rate of refrigeration house and utilization rate of refrigeration house volume.

Table 4. Analysis of gray correlation between input index and output inde

Degree of correlation	Number of logistics staff	Quality of logistics staff	Training of logistics staff	Mobility of logistics staff	Logistics quantity of food	Total value of circulating food
Timeliness ratio of goods collection	0.56	0.72	0.54	0.52	0.52	0.71
Timeliness of goods delivery	0.52	0.78	0.59	0.53	0.52	0.56
Logistics income	0.72	0.62	0.51	0.72	0.63	0.51
Total logistics cost	0.51	0.52	0.58	0.74	0.84	0.51
Satisfaction degree of producer	0.50	0.52	0.74	0.78	0.61	0.51
Satisfaction degree of retailer	0.50	0.52	0.91	0.55	0.53	0.51
Number of producer	0.67	0.60	0.50	0.50	0.50	0.75
Number of retailer	0.71	0.65	0.51	0.51	0.51	0.90
Rate of sales return	0.50	0.51	0.57	0.78	0.78	0.51

Input element which has the closest correlation with satisfaction degree of client include training rate of logistics staff, number of refrigerator, utilization rate of refrigeration house area and utilization rate of refrigeration house. Details are shown in Table 5.

Table 5. Input index that plays key effect on operation of system

Logistics safety	Quality of logistics staff, number of refrigeration vehicle, investment amount of information system and utilization rate of refrigeration house area
Logistics efficacy	Quality of logistics staff, food logistics quantity, number of refrigeration vehicles, utilization rate of refrigeration house area and investment amount of information system
Total logistics cost	Total amount of circulating food value, number of refrigeration vehicle, utilization rate of refrigeration house area and volume
Client satisfaction degree	Training rate of logistics staff, number of refrigerator, utilization rate of refrigeration house area and utilization rate of refrigeration house

Gray information table for empirical food cold chain logistics system is generated based on index system representing operation state of system (Table 6).

Table 6. Gray information table of empirical food cold chain logistics system

Time	Quality of logistics staff	Number of refrigeration vehicle	Investment amount of information system	Satisfaction degree of retailer	Total logistics cost
1	[7.5,11.8]	[6,6]	[1.0,1.5]	[95,96]	[38,40]
2	[10.6,12]	[10,10]	[1.5,1.5]	[94,95]	[37,39]
3	[7,10]	[13,13]	[2.0,2.0]	[93,95]	[33,37]
4	[8,10]	[20,20]	[2.0,2.0]	[94,96]	[30,35]
5	[9,11]	[20,20]	[3.0,3.0]	[94,98]	[30,32]
6	[11,12]	[20,20]	[3.0,3.0]	[94,95]	[28.30]

Data in Table 6 is first given standardization processing with gray range transformation formula; then ideal state vector of empirical food cold chain logistics system is calculated. Then gray interval correlation coefficient matrix corresponding to ideal state at different evaluation stage is constructed, as shown in Table 7 ($\lambda = 0.5$).

Table 7. Gray interval correlation coefficient matrix of evaluation object

$$(r_{ij}^{+})_{6\times 8} = \begin{bmatrix} 0.606 & 0.332 & 0.332 & 0.700 & 0.358 & 0.645 & 0.332 & 0.386 \\ 0.891 & 0.412 & 0.400 & 0.532 & 0.453 & 0.564 & 0.332 & 0.445 \\ 0.467 & 0.500 & 0.500 & 0.532 & 0.562 & 0.564 & 0.332 & 0.551 \\ 0.552 & 1.000 & 0.500 & 0.668 & 0.635 & 0.708 & 0.332 & 0.680 \\ 0.612 & 1.000 & 1.000 & 0.832 & 0.875 & 1.000 & 1.000 & 0.825 \\ 1.000 & 1.000 & 1.000 & 0.532 & 1.000 & 0.502 & 1.000 & 1.000 \end{bmatrix}$$

Though calculation, we get index weight
$\eta = (0.158, 0.125, 0.096, 0.145, 0.123, 0.152, 0.072, 0.125)$

Average value of system state at different quarter is (0.208, 0.335, 0.355, 0.542, 0.774, 0.717). Estimated value of empirical food logistics cold chain system in 18 months can also be obtained, as shown in Figure 3. Though empirical cold chain logistics cooperative system shows fluctuation and unordered state at some time point, overall state shows a rising tendency.

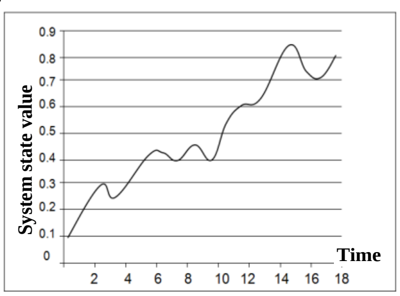

Figure 3. Evaluation value of empirical food cold chain logistics system state

System state can be divided into good, general and not ideal. White function of three gray categories is constructed as follows.

$$f_j^1(r) = \begin{cases} 0 & r < 0.6 \\ \dfrac{r-6}{0.2} & 0.6 \le r \le 0.8 \\ 1 & r > 0.8 \end{cases}$$

$$f_j^2(r) = \begin{cases} \dfrac{r-0.4}{0.2} & 0.4\, r \le 0.6 \\ \dfrac{0.8-r}{0.2} & 0.6 \le r \le 0.8 \\ 0 & r \notin [0.4, 0.8] \end{cases}$$

$$f_j^3(r) = \begin{cases} 1 & r < 0.6 \\ \dfrac{0.6-r}{0.2} & 0.6 \le r \le 0.8 \\ 0 & r > 0.8 \end{cases}$$

Through calculation, it is found that, cooperative operating state of empirical food cold chain logistics system in the first and second quarter is not ideal; cooperative operating state in the third and fourth quarter is general; operating state in the first and second quarter in the next year is good.

4. Conclusions

To sum up, food cold chain logistics system cooperation refers to member enterprises realize seamless joint of various logistics links through mutual cooperation, information resource share and complementary advantage when food circulates from supply source to reception source, thus to ensure food safety, improve operation efficacy of cold chain logistics operation, lower logistics cost, optimize food economical efficiency and enhance satisfaction degree of clients. We make an overall analysis and study on food cold chain logistics rough set model based on gray similar correlation relationship and its application and prove the innovation and practical meaning of this study by evaluating system cooperative state and analyzing key index with gray system theory and rough set methodology.

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