Grey Relation Entropy based Dynamic Evaluation Model of Product Lifecycle Information System Evolution

Shi-yi Zhao, Zi-jian Liu*, Yi-nan Li

***Abstract*—Based on its assumption product lifecycle information system is a dissipative structure, the product information model of different product lifecycle phase is regarded as the main research subject, and the time for establishing accurate and perfect product information model is regarded as the order parameter to describe the order and evolution direction of a system. The dissipative structure theory and grey system theory are applied to establish the determination model based on grey relation entropy and provide new evaluation methods for product lifecycle information system as well as theoretical foundation for system optimization design and adjustment. The model is applied in the evaluation of CAPP system evolution in a company. The feasibility of the evaluation method and the model is verified by the results.**

***Index Terms*—grey relation entropy; product information model; product lifecycle information system; dissipative structure**

I INTRODUCTION

Product Life-cycle Information System (PLIS) is the result of IT and manufacturing development. The emergence and development of PLIS gives great impact on the development of manufacturing and its importance is widely recognized. But the benefit of PLIS can not completely acquit itself because it's very difficult to grasp the essence and discipline due to PLIS's complexity. Now it's very urgent for us to expound the basic character of PLIS and put out new theory to guide practice[1][2][3]. In this paper, dissipative structure theory, information entropy, synergetics theory and grey relation entropy are introduced into PLIS and the direction of system development is judged according to the relations between the entropy-reducing (or the entropy-increasing) and the sequence in the dissipative structure.

The concept of "dissipative structure" is put forward by Prigogine. Prigogine and others pointed out that the open system which is far from equilibrium constantly exchanges substance and energy with the environment. When the parameter of the system change achieves a certain threshold, the state of the system will change abruptly from the disorder state or low order state to a new order state of time, space and function. The new macroscopically stable order structure is a dissipative structure. Dissipative structure needs four conditions: (1)The system must be open, that is to exchange substance and energy with environment;(2)System must be non-equilibrium, Prigogine points out "non-equilibrium is the source of order"; (3) Factors of system exits nonlinear interaction mechanism; (4) System uses fluctuation from disorder to order. Since dissipative structure was founded, it has been widely used in many fields such as physics, biology, chemistry, economy, society, and obtains a series of fruits[4].

PLIS is a complicated system and possesses all the qualifications which forming dissipative structure. Firstly PLIS is a big open system. There exist substance flow, energy flow, and information flow between the system and the external environment driven by the users' requirements ,profit and operators' manipulation, control as well as decision. Secondly, PLIS is far from equilibrium. Equilibrium has the characters that all elements are simple and of maximum entropy and highest disorder. PLLS maintains order in aspects of time, space and functions, and meet users' demands orderly. Therefore, the PLIS is far away from the equilibrium state. PLIS is a very big complicated system, it comprises subsystems such as product needs analysis, concept design, structure design, engineering analysis, manufacture and service support, and so on. The objective of PLIS is to combine all the resources organically, to get perfect resources scheme, and achieve the best profit. This input and output is not simple linear value accumulation, it is the outcome of complicated and netlike interaction mechanism of all factors. Only is there nonlinear interaction among all elements, can PLIS meet users' demands. In addition PLIS is consistently affected by the factors such as the demands of users, elevation of expectation for benefit as well as the development of IT. In order to meet the demands of users and chase the greatest benefit numerous "little fluctuation" comes into being. When the influence of fluctuation reaches a certain level, the system will produce "large fluctuation", change abruptly from current state to a much more order state and form new dissipative structure, and thus ceaselessly push the development of PLIS. So PLIS cannot but obey the principle of dissipative structure theory.

German physicist R. Clausius made the ratio of the absorb thermal and temperature in the irreversible process of the material as the entropy, and he also discovered an important

Manuscript received March 22, 2008. This work was supported by Major Program of National Natural Science Foundation of China(No. 60635020)

Shi-yi Zhao is with State Key Laboratory of Advanced Design and Manufacture for Vehicle Body, Hunan University, Changsha 410082 China(e-mail:zsywelcome@163.com)

*Corresponding author:Zi-jian Liu is with State Key Laboratory of Advanced Design and Manufacture for Vehicle Body, Hunan University, Changsha 410082 China(phone: +86-731-8823938;e-mail: hncad@hnu.cn)

Yi-nan Li is with SAIC Motor Technical Center, Shanghai 201206 China(e-mail:yinan@shauto.com.cn)

nature of entropy. Entropy change is a state function which is thermodynamic path-independent and only depends on the initial state and the terminal state. Once the state of a system is certain, the value of its entropy remains unchanged. In 1948, Shannon introduced the concept of entropy to the information theory and used entropy to measure the uncertainty, stability and the quantity of the information. Information is a measure of the degree of order, and entropy is a measure of the degree of disorder of a system. Both of them have equal absolute values but with opposite signs.

According to Shannon's entropy definition [5], suppose we have an event P with n possibilities whose probabilities of occurrence are $p(x_i)$, the entropy of this event is represented in formula (1).

$$H(P) = -\sum_{i=1}^{n} p(x_i)\log p(x_i) \quad (1)$$

The relationship between entropy and the degree of order is that system with high entropy is low order or high disorder; instead, the high order system has low entropy. Thus, based on the relationship between entropy and order, the entropy value can be used to describe the order degree of the product lifecycle information system and estimate its evolution direction.

PLIS is an organism which consists of subsystems such as product needs analysis, concept design, structure design, engineering analysis, manufacture and service support and so on. Every subsystem has its own evolution discipline and is constrained by other factors. These subsystems interact, synergize and restrict each other. This relationship affects the structure of the system and determines the mechanism and evolution discipline of the system.

The order of PLIS means every subject of the system remains certain order; in more details, product needs model, concept model, design model, analysis model, manufacture model and service model can carry and distribute the information needed in the design process, and efficiently transfer the correct and complete information to the users who are thirsty for the information[6][7]. Product lifecycle information system dissipative structure shows that the order of the system is dynamic. The system evolving from low to high is either the process of forming dissipative structure or the process of transforming from one dissipative structure to another. But the phase transition of the system does not always move towards new order, it can also move towards disorder. Order and disorder can transform to each other. Therefore we should describe the order degree of the system first, if we want to research whether the system evolves towards order or disorder.

In dissipative structure, the parameter which controls the change of the other parameters and thus dominates the evolution of the whole system is called order parameter, which determines degree of order in a system. So order degree and evolution direction of a system can be described by the order parameter. The result of "synergetic theory" research indicates that synergy results in order, non-synergy results in disorder. Since order parameter determines the evolution direction of a system, the synergy of inner parameters in a system is the key mechanism for the evolution from disorder to order. In PLIS product information model is the carrier of the information needed during the product designing processes. The performance, process, and decision-making of the system are mainly determined by the product information model and the corresponding operation. Therefore, product information models are the most important subjects in the research of system evolution. Whether PLIS is in order or not depends on the product information model and the corresponding operation of the subsystems, such as product needs analysis, concept design, structure design, engineering analysis, manufacture, service support, and so on, can cooperate with each other or not. The level of cooperation determines the characters and rules of PLIS's phase transition. The degree of cooperation can be judged by the time needed during the construction and operation of the product information model. The better the factors of PLIS cooperate, the shorter the time needed for constructing and operating product information model, completing the distribution and share of corresponding product data, knowledge as well as conveying the correct, perfect product information to the users who most need it. Therefore the time needed for constructing a correct and perfect product information model which meets users' demands is used as an order parameter to describe the order and evolution direction of system.

According to the principle of grey relational analysis of grey system theory[8], PLIS is considered as a type of grey system due to the randomicity and uncertainty when applying the product information model and information carried to meet the demands of users. Based on the agreement between the theoretical time and the actual time during construction and operation of the product information model, grey relation coefficient is used to quantitatively describe the relativity between the actual time and the expected time from the users. Apparently, with higher coefficient, the PLIS can convey the information more efficiently to the users who most need it, the description of information and the convey efficiency are more reasonable, and thus the system is in higher order. But the application of product information system in PLIS has the characters of multi-phase and multi-purpose, and there is difference between product information system of various phases and purposes, there are a lot of grey relational coefficients calculated and one single grey relational coefficient cannot reflect the change discipline of the whole PLIS. In this article the result of the grey relational coefficient is denoted by entropy, and the evolution direction is judged by the entropy change of different periods.

II. Methodology

The main procedure of GRA is firstly translating the performance of all alternatives into a comparability sequence[9]. This step is called grey relational generating. According to these sequences, a reference sequence is defined. Then, the grey relational coefficient between all comparability sequences and the reference sequence is calculated. Finally, based on these grey relational coefficients, the grey relational entropy between the reference sequence and every comparability sequences is calculated. The details of the proposed GRE procedure is presented below.

Step 1: *Grey relational generating*

Processing all performance values of every alternative into a comparability sequence, in a process analogous to normalization, is necessary. This processing is called grey relational generating .Define x_i for the time needed for constructing and operating a correct and perfect product information model by the ith user, and $\mathrm{X} = (x_1, x_2, ..., x_n)$ for the time sequence.

$$x_i^{\bullet} = (\max(x_k, k = 1,2,...,n) - x_i) / (\max(x_k, k = 1,2,...,n) - \min(x_k, k = 1,2,...,n)) \quad i = 1,2,...,n \quad (2)$$

Equation (2) is used for the-smaller-the-better attributes.

Step 2: *Reference sequence definition*

After the grey relational generating procedure using equation (2), all performance values will be scaled into [0,1]. For an time attribute x_i, if the value $x_i^{\bullet}$ which has been processed by grey relational generating procedure, is equal to 1, or nearer to 1 than the value for any other time attribute, that means constructing and operating the ith product information model is more efficiently than any other. Therefore, we then consider the time series $\mathrm{X}_0 = (1,1,...,1)$. This is termed the reference sequence.

Step 3: *Grey relational coefficient calculation*

Grey relational coefficient is used for determining how close $x_i^{\bullet}$ is to x_{0i}. The larger the grey relational coefficient, the closer $x_i^{\bullet}$ and x_{0i} are. The grey relational coefficient can be calculated by equation (3)

$$r_{0i}(i) = \frac{\Delta\min + \zeta\Delta\max}{\Delta_{0i} + \zeta\Delta\max}, i = 1,2,...,n \quad (3)$$

Where $r_{0i}(i)$ is the grey relational coefficient between $x_i^{\bullet}$ and x_{0i}, and $\Delta_{0i} = \left|x_i^{\bullet} - x_{0i}\right|$, $\Delta\min = \min\{\Delta_{oi}\}$, $\Delta\max = \max\{\Delta_{oi}\}$, $\zeta \in (0,1]$ is the coefficient to distinguish the degree of proximity of X_0 and X. This value can be adjusted based on the actual system requirements.

In equation (3), greater correlation coefficient means that time needed for users to establish an accurate and complete product information model and finish corresponding operation will have less difference from the expectation time. But there are many Gray coefficient calculated, each factor can only reflect the match level of corresponding user product information model and actual product information model. It can not indicate the product life cycle information system as a whole.

Step 4: *Grey relational entropy calculation*

According to the information entropy concept supposed the sequence $X = (x_1, x_2, \cdots, x_n)$, $x_i \geq 0$,and $\sum x_i = 1,$ function $S(X) = -\sum_{1}^{n} x_i \log x_i$ is regard as the grey relational entropy of sequence X, x_i for the attribute information. The grey relational entropy $S(X)$ of the sequence X has the same value with Shannon entropy function. Therefore, grey relational entropy $S(X)$ of the sequence X has the all characters of Shannon entropy.

Suppose that Y is the reference sequence and X is the comparison sequence. $R_j = \{r_x(t) \mid k = 1,2,...,n\}$. The mapping

$$R_j \to P_j, p_h(t) = \frac{r_h(t)}{\sum_{k=1}^{n} r_k(t)} \quad (4)$$

$p_h(t) \in P_j$, $h = 1,2,\cdots,n,$ is called the grey relational coefficient distributing mapping, and the p_h is called the density value of distribution.

According to the definition of grey relational entropy and grey relational coefficient distributing mapping, the grey relational entropy can be expressed as:

$$S(t) = -\sum_{k=1}^{n} p_h(t) \log p_h(t) \quad (5)$$

$$\Delta S = S(t+1) - S(t) \quad (6)$$

If $\Delta S > 0$, the total entropy of the system increases. That means the establishment, edit, acquisition, transmission of the accurate, complete information model in the product life cycle information system as well as the exchange and sharing of information between the different models can not be carried out promptly and effectively, the degree of disorder increases and control measures are needed.

If $\Delta S < 0$, it indicates that the overall entropy of the system decreases, the establishment, edit, acquisition, transmission of the accurate, complete product information model in the product life cycle information system as well as the exchange and sharing of information between the different models can be carried out promptly and effectively. The elements of the system synchronize well, order is enhanced, product life cycle information system is in a sound development and evolution process, and user's demands can be reasonably met.

If $\Delta S = 0$, it indicates that entropy stays unchanged within a certain period, the system state is the same as the beginning. At this time further in-depth research of the system is needed, and technology strategy adjustments should be made to make the evolution directed towards negative entropy.

III ILLUSTRATIVE APPLICATION

CAPP is one of the important PLISes. In this article the above dynamic evolution evaluation model of PLIS is testified by a company's CAPP system evolution[10]. The initial CAPP system of this company was developed based on the Variation CAPP ideas and aimed at the automotive transmission gears and shaft. With the development of IT and CIMS engineering, the company demands more application of CAPP and requires higher intelligent integration of information and process. To solve the problems of the initial CAPP system, such as low-capacity, time consuming, and

ISBN:978-988-17012-3-7

inconvenience during amendment of the process, HDCAPP expert system is developed. HDCAPP expert system constructed process knowledge library and established the reasoning machine by direct reasoning and Rete pattern matching algorithm match pattern, thus greatly improved the reliability of process knowledge, the reasoning quality, and the efficiency for searching and editing the process.

Table 1. The time, grey relational coefficient in original CAPP and CAPP expert system

Part No.	T_1(h)	T_2(h)	R_1	R_2
Shaft_01	2.0	1.2	1.00	1.00
Shaft_02	2.5	1.2	0.75	1.00
Shaft_03	3.0	1.2	0.60	1.00
Gear_01	4.5	2.8	0.38	0.38
Gear_02	4.6	3.0	0.37	0.36
Gear_03	4.8	2.8	0.35	0.38
Gear_04	4.5	3.0	0.38	0.36
Gear_05	4.7	3.2	0.36	0.33
Gear_06	4.8	3.1	0.35	0.34
Gear_07	4.2	3	0.41	0.36
Gear_08	4.4	2.9	0.38	0.37
Gear_09	4.2	3.0	0.41	0.36

In table 1, T1 and T2, respectively, is the time needed for constructing and operating a correct and perfect product processing information model which meets user's needs in the original CAPP, HDCAPP expert system; R1, R2, respectively, is the corresponding grey relational coefficient in the original CAPP and HDCAPP Expert System by (2), (3). Using equation (4) and (5) can obtain respectively grey relational entropy in the original CAPP, HDCAPP Expert System.

$$S(t) = 1.049, S(t+1) = 1.025,$$
$$\Delta S = S(t+1) - S(t) = -0.024 < 0$$

According to the dynamic evaluation model of the product life cycle information system evolution, when $\Delta S < 0$, it means this enterprise's Automotive Transmission HDCAPP expert system is better than the original CAPP system, the total system entropy decreases. In product technology HDCAPP expert system, the establishment, edit, acquisition, transmission of the accurate, complete information model in the product life cycle information system as well as the exchange and sharing of information between the different models can be carried out promptly and effectively. The elements of the system synchronize well and order is enhanced. The HDCAPP expert system is in the process of sound development and evolution, users' demand can be reasonably met. The assessment results agree with the actual performance.

REFERENCES

[1] *WANG Bo-tao, SHU Hua-ying. A study of IS evolution based on self-organization theory.Journal of BUPT (Social sciences Edition), 2006,8(1): 43-47.(in Chinese)*

[2] *MA Xin-li. On the self-organization mechanism of manufacturing system. Journal of Shaanxi Institute of Technology, 2003, 19 (1):52-55. (in Chinese)*

[3] *GONG Zhu-ping.The relationship between the evolvement of manufacturing information system and dissipative structure. Journal of information,No.1,2007:79-85*

[4] *Wang Ren-yi, XU Jun, ZHANG Yu-rong. The Reservoir Performance Assessment Model Based on Dissipative Structure Theory. Xinjiang Petroleum Geology,2006,27(3):324-327.*

[5] *C.E.Shannon, A mathematical theory of communication, Reprinted with corrections, The Bell System Technical Journal 27,379-423,623-656,(1948).*

[6] *SHU Qi-lin, WANG Cheng-en. Research on information model for product lifecycle. Computer Integrated Manufacturing Systems, 2005,11(8):1051-1063. (in Chinese)*

[7] *Zhang Xiangfeng. Research on Framework for Product Data Supporting the Product Lifecycle. China Mechanical Engineering. 2004,15(9):803-805.(in Chinese)*

[8] *Deng,J,Introduction to grey system theory.Journal of Grey Systems,1989 ,1, 1–24.*

[9] *Hu Fang, Huang Jianguo, Zhang Qunfeng. A Method for Effectiveness Evaluation of Underwater Vehicles Based on Grey System Theory. Journal of Northwestern Polytechnical University.2007, 25(3):411-415.*

[10] *LI Yi-nan. Research on the CAPP Expert System-HDCAPP, Hunan Univerdity Master thesis,2003,11.(in Chinese)*