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The Research of Design Dynamics on Behavior Flow Ecosystem

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Abstract

We analyze the current product design modeling background and status, combined with the design dynamics, propose more intelligent design of the product behavioral modeling, by analogy Ecosystem, proposed the concepts and design framework product flow behavior and product behavior flow of the ecosystem. Proposed the concepts of design entropy flow and conservation in design dynamics, put forward a hybrid Petri nets to describe the flow behavior and formal product ecosystem model, a hybrid Petri net is given to the behavior flow ecosystem model and analyze engine and the design entropy.

Keywords: *physical state, behavior flow, behavior flow ecosystem, the design entropy, design dynamics, Petri net*

1. Introduction

The main development direction of modern industrial design is intelligent, integrated [1]. From the view of essence of the design, the product design process to achieve specific objectives in a complex relationship between constraints and abstract’s implementation process, the main product design process can be divided into conceptual design, assembly frame design, detailed design [2], where the concept of product design is the most important part of the basis of common conceptual design theory Qian.L and Gere.JS's FBS model [3], Axiomatic design theory proposed by Suh NP [4], Jin-Xizhe proposed the FBS model, which using neural network expert system for training [5], Guang-Jun Zhang, Guo-Dunbing and others established of improved function in axiomatic design tree [6]. There are also many scholars to introduce genetic algorithms or extensions in the product concept design matrix [7] or the function solution of the conceptual design [8] ,The existing problems of conceptual design is that the product concept design from function view is often reflected by the product designer's cognitive and the subjective factors such as understanding of function of product and the division function-structure, At present, the product conceptual design mainly focus on the function orient design, but there is a huge blank in the research of product behavior and behavior mechanism.

In dealing with the complex behavior relationship in behavior layer and energy flow, from the view of ecological theory system, that the ecological theory should learn from biological evolution, take the ecosystem as a complex system composed of intelligent modules to study [9], Behavior unit is the basic unit of the product modeling ecosystem. Behavior unit gathering behavior community, in the driven ofdesign power, the behavior communities interact with each other through information transfer, energy flow and material exchange, gather to constitute the parent behavior community, In this dynamic movement, achieve the progressive construction of product model.

Based on the behavior of product analysis and research, proposed a new product modeling method based on the product behavior flow ecosystem framework, proposed the definition of behavior flow and hierarchical framework under the behavior flow framework, used ecological approach to class behavior unit, achieve the transmission of information between behavior communities through Petri net, and did the research of design dynamic, the behavior of the product flow through the product features and structural mapping of changes in the final completion, solve the traditional product model design problems, for the purpose of intelligent design and evolution.

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2. Product Behavior Flow Ecosystem Model

The design framework of product behavior flow ecosystem is shown in Figure 1. In the behavior flow ecosystem design process, the downward direction is from the behavior of the product-functions to achieve the objective to the subjective mapping, the upward direction is the product behavior-structure mapping product behavior of the material to achieve. The horizontal direction shows the modeling process of behavior flow ecological models, the behavior unit iterative merging to behavior community, behavior community combine with the state of the material in the same level, through the ecosystem material conversion, information transfer and energy flow, the behavior continue to strengthen community maturity, while the functional layer in the vertical direction is function unit to sub-functions, the formation of various sub-functions consist the final function, structure layer is from abstract to concrete by corresponding products from the structure library, finally form a concrete structural products.

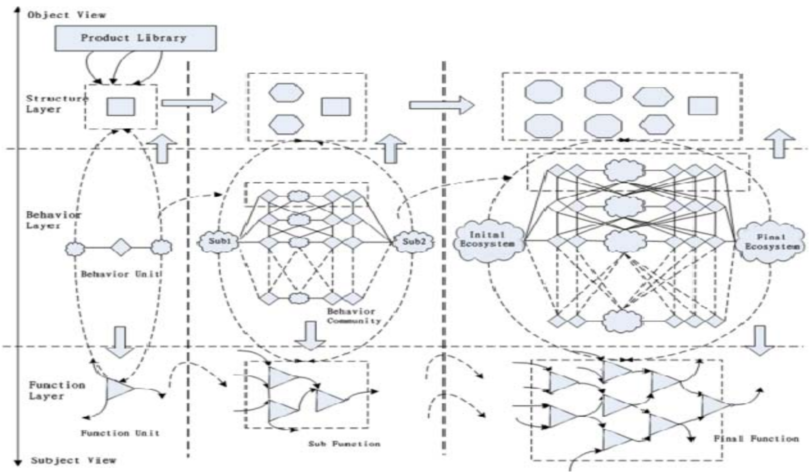


Figure 1. The Design Framework of Product Behavior Flow Ecosystem

2.1. Behavior

Based on the references [10-13], behavior is a change that operating state of an object, assuming that the operation object can be divided into initial state and target state, behavior is the connection process of operated object changing from the initial state to target state. Behavior is by the operation in product of material state; define the product state material, collection M, including the products material states.

$$M_{in} = \bigcup_{i=1}^{n} M_i = \left(M_0, \ldots, M_n\right) \tag{1}$$

$$M_{out} = \bigcup_{i=j}^{k} M_i = \left(M_j, \ldots, M_k\right) \tag{2}$$

Define **behavior** as β ,so $\beta\, M_{in} = M_{out}$,then $\beta = M_{out} / M_{in}$

2.2. Behavior Flow

Such as the A part mentioned, the molding process is a fluid process, in the time line from initial state to final state, the connection status of all operations on behavior is a fluid in the concept of time, the state of product structure in accordance with specific time and space in order to change the order of occurrence of the state, resulting in a series of the completion the sub-functions, and complete the total specific functions finally, we define the behavior flow:

$$\beta_n \beta_{n-1} \cdots \beta_1 \left(M_1, \ldots, M_{n-1},\ \ M_n\right) \to F \tag{3}$$

$F \subset \bigcup_{i=1}^{n} F_i$, $\lim_{i \to n} \bigcup_{i=1}^{n} F_i \Rightarrow \sum_{i=1}^{n} F_i$, F is the function in the product modeling, $(M_1, \dots, M_{n-1}, \ M_n)$ is the input state of product behavior flow, we define $B = \beta_n \beta_{n-1} \cdots \beta_1$.

2.3. Material State

Material isobjective carrier to handle the operated objects, The material state is the collection of material, space, time in the behavior operating process, we define material in the product behavior flow ecosystem is the object of behavior operated, so the material state can be defined as: M=(T, m, S, P)

(1) (T, m, S) is the collection of material, T_i represent the type of material, m is the amount of material, $S = (s, g, l, S^*)$, $S^* = \bigcup_{i=0, j=0, k=0}^{n} s_i g_j l_k$, respectively represents solid, gaseous, liquid, S^* is mixed state.

(2) $P = (P_i, P_{in}, P_{out}, i = 1, 2, \dots n)$, P_i represent the location of the material, P_{in} represent input location, P_{out} represent output location.

2.4. Behavior Community and Behavior Ecosystem

Definition 1: Minimum design time: the basic time of product behavior divide to behavior unit in behavior flowecosystem.

Definition 2: Parallel behavior: for any two product material middle states M_i,M_j there is a series of operations between them, we define the behavior flow in the time reflectionBF_i,and we define parallel behavior as behaviors occurring at the same, then:

$$\mathbf{B}_j = \lim_{t \to t_0} \begin{pmatrix} \beta_{k0} & \beta_{k+1,0} & \beta_{k+2,0} & \cdots & \beta_{j-1,0} & \beta_{j,0} \\ \beta_{k1} & \beta_{k+1,1} & \beta_{k+2,1} & & \beta_{j-1,1} & \beta_{j,1} \\ \beta_{k2} & \beta_{k+1,2} & \beta_{k+2,2} & & \beta_{j-1,2} & \beta_{j,2} \\ \vdots & & & \ddots & & \vdots \\ \beta_{kt} & \beta_{k+1,t} & \beta_{k+2,t} & \cdots & \beta_{j-1,t} & \beta_{j,t} \end{pmatrix}$$

Definition 3: Behavior community: occurs some behavior parts corresponding to parallel behavior, we define behavior community as the behavior combination corresponding to behavior flow space. We define it as C, then:

$$B_i = \begin{pmatrix} \mathbf{B}_{11} & \mathbf{B}_{12} & \mathbf{B}_{13} & \cdots & \mathbf{B}_{1,j-1} & \mathbf{B}_{i,j} \\ \mathbf{B}_{21} & \mathbf{B}_{22} & \mathbf{B}_{23} & & \mathbf{B}_{2,j-1} & \mathbf{B}_{i,j} \\ \mathbf{B}_{31} & \mathbf{B}_{32} & \mathbf{B}_{33} & & \mathbf{B}_{3,j-1} & \mathbf{B}_{i,j} \\ \vdots & & & \ddots & & \vdots \\ \mathbf{B}_{i,2} & \mathbf{B}_{i,j} & \mathbf{B}_{i,j} & \cdots & \mathbf{B}_{i,j-1} & \mathbf{B}_{i,j} \end{pmatrix} = C_i \text{ Occurs } \lim_{i \to i_0} \begin{pmatrix} \beta_{11} & \cdots & \beta_{1i} \\ \vdots & \ddots & \vdots \\ \beta_{j1} & \cdots & \beta_{ji} \end{pmatrix} = \lim_{i \to i_0} C_{i_0} = \beta_{i_0}$$

Character 1: $\exists$ Behavior community C_i ,the current material carrier M_i has the sub-function in behavior flow ecosystem.

ProveExisting C_i ,then:

$$C_i = \begin{pmatrix} \mathbf{B}_{11} & \mathbf{B}_{21} & \cdots & \mathbf{B}_{i1} \\ \mathbf{B}_{12} & \mathbf{B}_{22} & & \mathbf{B}_{i2} \\ \vdots & & \ddots & \vdots \\ \mathbf{B}_{1i} & \mathbf{B}_{1i} & \cdots & \mathbf{B}_{ii} \end{pmatrix},$$

Assuming the current material carrier M_i, then:

$$\begin{pmatrix} \mathbf{B}_{11} & \mathbf{B}_{21} & \cdots & \mathbf{B}_{i1} \\ \mathbf{B}_{12} & \mathbf{B}_{22} & & \mathbf{B}_{i2} \\ \vdots & & \ddots & \vdots \\ \mathbf{B}_{1i} & \mathbf{B}_{1i} & \cdots & \mathbf{B}_{ii} \end{pmatrix} M_i \Leftrightarrow \beta_n \beta_{n-1} \cdots \beta_1 M_i \to F_i$$

F_i is the sub-function in the behavior flow ecosystem.

Definition 4: Behavior community maturity degree: Wedefine behavior communitymaturity degree as the coupling degree of the current behavior flow ecosystem structure and the sub-function of the product; we said a product is mature when it satisfies the conceptual design definition, assuming existing behavior community C_i, C_j, C_k, existing:

$$\begin{pmatrix} \beta_{11} & \cdots & \beta_{1i} \\ \vdots & \ddots & \vdots \\ \beta_{l1} & \cdots & \beta_{li} \end{pmatrix} \times \begin{pmatrix} \beta_{11} & \cdots & \beta_{1j} \\ \vdots & \ddots & \vdots \\ \beta_{m1} & \cdots & \beta_{mj} \end{pmatrix} = \begin{pmatrix} \beta_{11} & \cdots & \beta_{1k} \\ \vdots & \ddots & \vdots \\ \beta_{n1} & \cdots & \beta_{ni} \end{pmatrix}$$
$$\Rightarrow C_i \times C_j = C_k$$

Definition 5: In behavior flow modeling process, behavior flow is the drive shaft, the evolution of the ecosystem behavior flow is driven by the behavior flow, we define the behavior flow ecosystem E act as state behalf of the product behavior flow model in the process of forming, $E = C \otimes M$, E is combination of the current state of material M and processing M behavior flow community, $\otimes$ operators represents the combination in conceptual design.

2.5. Design Entropy in Behavior Ecosystem and Design Dynamics

Definition 6: Product polymerization potential energy Ψ : the material product of state potential energy in space and state.

Definition 7: Design power potential energy Φ: The activeimplementation energy in the product design process through the operation subject to operation object energy

Definition 8: Design entropy S : The middle state of product behavior flow ecosystem modeling is constructing of Design power potential energy Φ and Product polymerization potential energy Ψ

Character 2: In the middle state of design entropy, the power potential to meet the design potential energy and part forming potential energy conservation.

Prove by definition 8, $S_i = S_j + \int_j^i d\Phi + \int_j^i d\Psi$, $\Delta\Psi = \Delta\Psi_1 + \Delta\Psi_2$, $\Delta\Psi_1$ is product forming potential energy, $\Delta\Psi_2$ is the waste state potential energy in product forming process, $S_i = S_j + \int_j^i d\Phi + \int_j^i d\Psi_1 + \int_j^i d\Psi_2$, in the design process $\Delta S = \int_j^i d\Phi + \int_j^i d\Psi_1 + \int_j^i d\Psi_2$ $\int_j^i d\Phi = \int_j^i d\Psi_1$, that is $\Delta S = \int_j^i d\Psi_2 \geq 0$, meet the principle of entropy increase.

In the behavioral flow ecosystem structure, product design power is carried by product structure, achieve the behavior of product features available in a complete system design process, the product structure process is from disorder to order, This is a decreasing entropy process, the increasing maturity only in a case of external power design, in order to promote the product mix to achieve the increasing maturity of any products for the modeling process, theautomatically process must provide external source power.

3. The Product Behavior Flow Ecosystem Establishment base on Hybrid Petri Net

As the references [14-19], based on the Petri net we define a net model to express product model. It is used to describe and analyze the continuous and discrete behavior during the behavior flow. The model introduces a token of continuous feature, adopting the dynamic equations to describe the varyingprocess ofcontinuous state of the system.

Define 9: Behavior flow Ecosystem system based on Hybrid Petri Net (BEHPN). We define $BEHPN=(P,T,A,R,C,M_0)$:

(1) $P=\{p_1,p_2,...,p_n\}$ is the finite set of state places, used to represent the state in the behavior flow ecosystem model. Including continuous state place P_C and discrete state place P_D, here $P=P_C\bigcup P_D, P_C\bigcap P_D=\varnothing$;

(2) $T=\{t_1,t_2,...,t_m\}$ is the finite set of behavior transition in the behavior flow ecosystem model used to correspond to the behavior. Including continuous behavior T_C and discrete behavior T_D, here $T=T_C\bigcup T_D, T_C\bigcap T_D=\varnothing$;

(3) A is the set of directed arc between state place and behavior, $A\in(P\times T)\bigcup(T\times P)$. It is used to express the direction of behavior flow;

(4) R is the set of whichcorrespond to and note the correlation equationcorrespond to continuous state place*p* as $R(p)$. Once $p\in P_C$ is marked, for, the property of continuous state vary according to $R(p)$.

(5) C isthe set of conditions corresponding to continuous behavior, the conditions corresponding to continuous behavior is denoted by $C(t)$

(6) M_0 is initial flag to express the system state at the beginning, that is the initial state of behavior flow.

BEHPN can model continuous and discrete part of a system in a same model framework. The continuous part includes continuous state place and continuous behavior and is used to describe the dynamic process of continuous variable varying.

4. The Engine Behavior Flow Ecosystem Model base on Hybrid Petri Net

Automobile engine is a typical hybrid system, the system not only include the continuous change of state parameters such as the output engine power, speed but also involves the discrete event such as the valves switch at a moment. In the behavior flow ecosystem model, we use the top-to bottom way in design, we divide Intake, Compress, Combustion, Outtake four behavior community, the physical structure abstract and behavior flow diagram of the engine is shown in Figure 2, 3, 4, 5 which includes: behavior community J, behavior community Y, behavior community R, behavior community P.

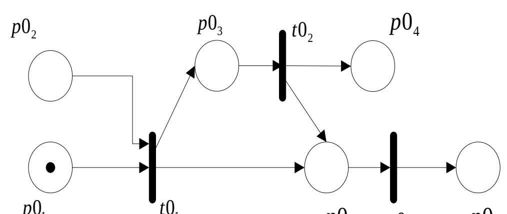


Figure 2. Behavior Community J: Intake Petri Net

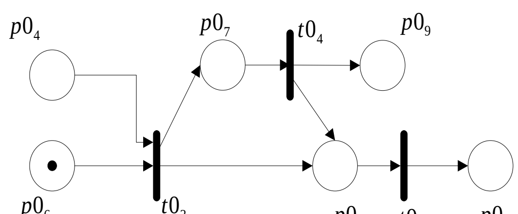


Figure 3. Behavior Community Y: Compress Petri Net

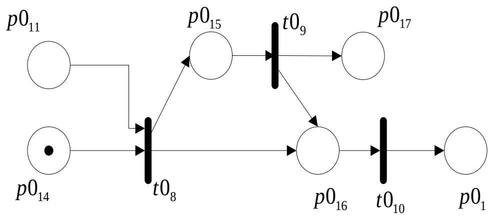


Figure 4. Behavior Community R: Combustion

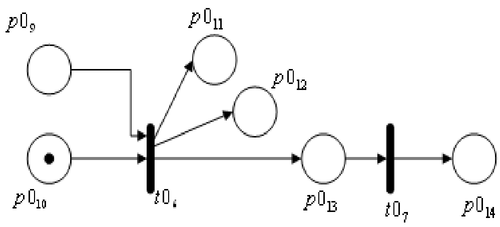


Figure 5. Behavior Community R: Outtake Petri

Behavior combination and state place in behavior community J Table1 and Table 2.

Table 1. Behaviors in Behavior Community J

Behavior	Condition or Event	Meaning
	Valve control	Outtake valve, intake valve
	Piston movement	Mixed gas input
		Intake ending

Table 2. State Places in Behavior Community J

Behavior	Condition or Event	Meaning
	—	Token:beginning of Intake
		Mixed gas input
		Internal state of mixed gas
		Press increasing in cylinder
	—	Volume increasing in cylinder
		Token: beginning of Compress

Behavior combination and state place in behavior community Y Table 3 and Table 4.

Table 3. Behaviors in Behavior Community Y

Behavior	Condition or Event	Meaning
	Valve control	Intakeclosed, Outtakeclosed
	Piston movement	Mixed gas compress
		Compress ending

Table 4. State Places in Behavior Community Y

Behavior	Condition or Event	Meaning
		Pressure, temperature decrease
		Mixed gas volume
	—	Mixed gas internal state
	—	Token: beginning of combustion

Behavior combination and state place in behavior community S Table 5 and Table 6.

Table 5. Behaviors in Behavior Community S

Behavior	Condition or Event	Meaning
	Fire mixed gas	Fire mixed gas, exploding
		Combustion ending

Table 6. State Places in Behaviour Community S

Behavior	Condition or Event	Meaning
	—	Pressure, temperature decrease
		Mixed gas volume
		Mixed gas internal state
	—	Token: beginning of combustion

Behavior combination and state place in behavior community P Table 7 and Table 8.

Table 7. Behaviors in Behavior Community P

Behavior	Condition or Event	Meaning
	Valve control	Intake opened, Outtake close
	Piston movement	Mixed gas output
		Outtake ending

Table 8. State Places in Behavior Community P

Behavior	Condition or Event	Meaning
		Pressure decreased
		Mixed gas volume decreased
	—	The remaining gas
	—	Token: beginning of intake

In Behavior community J, consumes the start signal Token, and then the external substances pass into the interior. When to meet the condition of transition, then end suction stroke and generate control signals (information substance) indicating that the beginning of compression stroke. In Behavior community Y, when entering the compression stroke, transition consumes the token, and begins to compress the input mixture to reduce the volume of mixture. In Behavior community S, Once, terminate the compressing stroke and generate the control signals indicating that the beginning of combustion stroke. When entering outstroke, it lets out the internal waste gas. In Behavior community P,terminate the outstroke and generate the control signals indicating that the beginning of outstroke. The circle once again begins.

Figure 6 is a full flow chart of four-cylinder engine, is the mixture state in state place, and the remains gas in the engine.

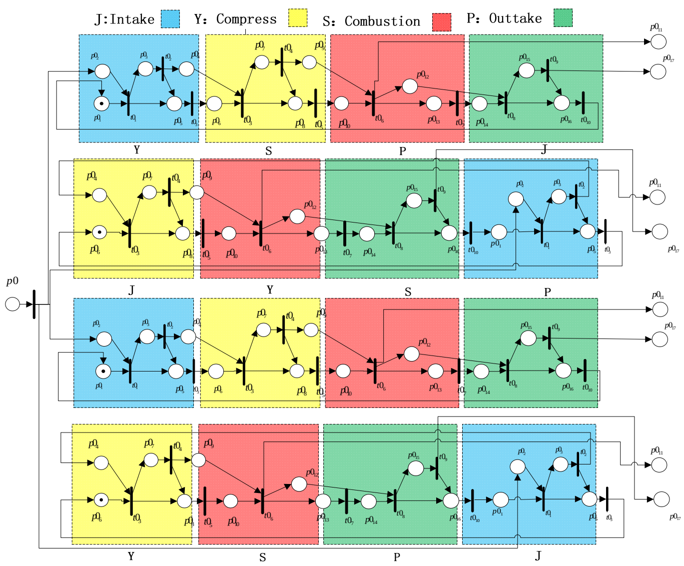
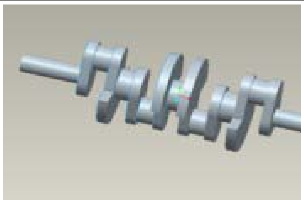
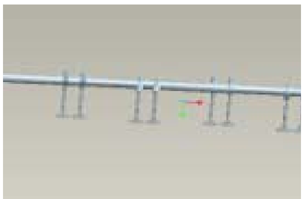
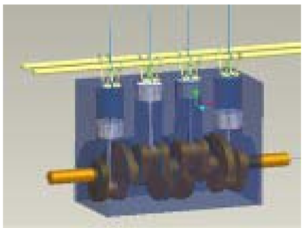


Figure 6. Four-cylinder Engines Petri Net Full Flow

According to behavior community division and the analog of Petri net of four-cylinder, combine by B, C concept, we give the instance of Inline four-cylinder car engine behavior flow ecosystem model, as Table 9.

Table 9. Inline Four-cylinder Car Engine Behavior Flow Ecosystem Model

State	Structure Carrier	Behavior Community	Parallel Behavior	Design Entropy Flow
MID		$\begin{pmatrix} \mathbf{B}_{1,1} & \mathbf{B}_{1,2} & \mathbf{B}_{1,3} \\ \mathbf{B}_{2,1} & \mathbf{B}_{2,2} & \mathbf{B}_{1,3} \\ \mathbf{B}_{3,1} & \mathbf{B}_{2,2} & \mathbf{B}_{x,x} \end{pmatrix}$	CONTACT_01_02 CONTACT_03_04 ROTARY_01 ROTARY_02 FIX_01	$S_1 \downarrow + \int_j^i d\Phi + \int_j^i d$
MID		$\begin{pmatrix} \mathbf{B}_{1,1} & \mathbf{B}_{1,2} \\ \mathbf{B}_{2,1} & \mathbf{B}_{x,x} \end{pmatrix}$	CONTACT_01 CONTACT_02 SNAP_01	$S_2 \downarrow + \int_j^i d\Phi + \int_j^i d$
MID		$\begin{pmatrix} \mathbf{B}_{1,1} & \mathbf{B}_{1,2} & \mathbf{B} \\ \mathbf{B}_{2,1} & \mathbf{B}_{2,2} & \mathbf{B} \\ \mathbf{B}_{3,1} & \mathbf{B}_{2,2} & \mathbf{B} \end{pmatrix}$	FIX_01_02 FIX_03_04 SNAP_01_02 SNAP_03_04 TRANSLATORY_01	$S_3 \downarrow + \int_j^i d\Phi + \int_j^i d$
MID		$\begin{pmatrix} \mathbf{B}_{1,1} & \mathbf{B}_{1,2} & \mathbf{B} \\ \mathbf{B}_{2,1} & \mathbf{B}_{2,2} & \mathbf{B} \end{pmatrix}$	SNAP_01_02 SNAP_03_04 TRANSLATORY_01 TRANSLATORY_02 FIX_01	$S_4 \downarrow + \int_j^i d\Phi + \int_j^i d$
MID		$\begin{pmatrix} \mathbf{B}_{1,1} & \mathbf{B}_{2,1} \\ \mathbf{B}_{1,2} & \mathbf{B}_{x,x} \end{pmatrix}$	FIX_01 CONTACT_01 SNAP_01	$S_5 \downarrow + \int_j^i d\Phi + \int_j^i d$
END		$\begin{pmatrix} \mathbf{B}_{11} & \mathbf{B}_{21} & \cdots \\ \mathbf{B}_{12} & \mathbf{B}_{22} & \\ \vdots & & \ddots \\ \mathbf{B}_{1i} & \mathbf{B}_{1i} & \cdots \end{pmatrix}$	（CONTACT) （ROTARY) （FIX) （SNAP) （TRANSLATORY) （ASSEMBLY)	$\Delta S = S_1 + S_2 + \cdots$ $\Delta\Phi = Designed$ $\Delta\Psi = Waste$

In the inline four-cylinder car engine behavior flow ecosystem model, parallel behaviors CONTACT、ROTARY、FIX、SNAP、TRANSLATORY、ASSEMBLY. On behalf of connection, rotating, fixed, bite, translation, assembly. Parallel behaviors sequence. There are basic unit of product modeling ecosystem, the aggregation of parallel behaviors construct behavior community, the behavior community use information exchanging, energy flow ways, construct father behavior community, by that dynamic flow, come to the end state of inline four-cylinder car engine model.

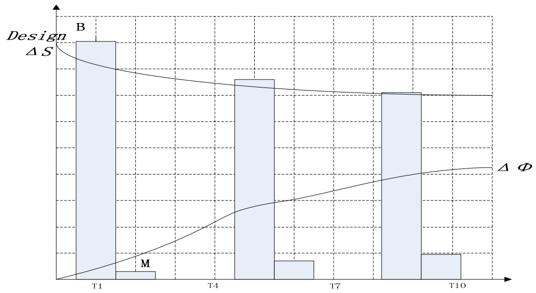


Figure 7. Changesin Design Entropy

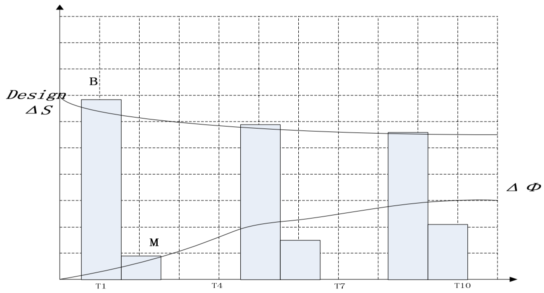


Figure 8. Changes in Design Entropy and Y

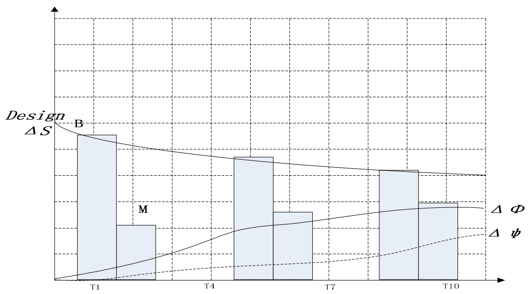


Figure 9. Change in Design Entropy

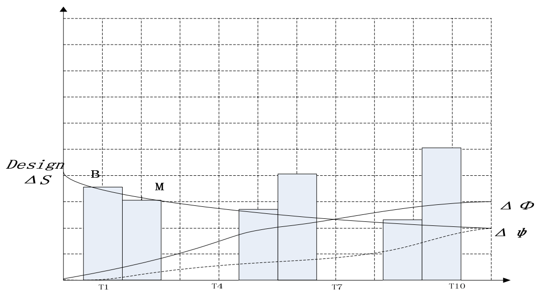


Figure 10. Changes in Design Entropy and P

As shown, the behavior flow ecosystem dynamics from the perspective of the design dynamics concerns the flow of entropy and behavior community change, behavior changes in behavior community of rectangular columns B indicates the size of community, M indicates the maturity of behavior community.

(1) The design entropy of behavior community J and Y reduce to the design power potential energy, the initial behavior community is very large, the scale of behavior community which meets the product design keep decreasing in the entropy flow process, conduct community begins to decrease, continue to conduct community maturity increased. Behavior Community J and Y acts only has design power potential energy, there is no waste aggregate potential energy.

(2) In behavior community S and P, the design entropy reduce to design power potential energy and waste aggregate potential energy, the scale of behavior keep decreasing, the maturity of behavior community comes to saturation. Part of design entropy change to waste aggregate potential energy.

(3) By Character 2, Product polymerization potential energyand Design power potential energy conservation, is product object state aggregate energy,is product waste state aggregate energy, design power potential energ yand waste state aggregate energy and design entropy part conservation.

(4) Evolution of natural communities is by the smallest unit's biological intelligent decision, In the product design process, the individual product does not exist independent intelligence, base behavior flow ecosystem theory, communities need to come to mature in the process by adding design entropy, in order to make product of independent evolution, the division of behavior community can be introduced into the algorithm to do accuracy analysis and training analysis, the process of design entropy accession process is irreversible.

5. Conclusion

Aim at the shortcomings of current focus on the conceptual product design features, this paper focuses on the study of product behavior designed dynamics, through the establishment of behavior flow based ecological communities, do research on the flow design entropy, describe the existing product model, this paper introduces hybrid Petri nets to modeling polymer behavior of the product, provides a precise mathematical model, give an instance of an engine to illustrate the proposed method. This paper proposes a design intelligent framework behavior based on the product behavior community, Product design dynamic were demonstrated on theory, we focusing on description of behavior community-based product modeling, but in another important aspect of the intelligence design cycle, the behavior of communities on the new product design modeling and quantitative analysis of entropy, we need following further study.

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References

[1] Suh Nam Pyo. Axiomatic Design: Advances and Applications. New York: Oxford University Press, 1999
[2] Qian L, GeroJS. Function-behavior-structure Paths and their Role in Analogy-based Design, ArtificialIntelligence for Engineering Design. *Analysis and manufacturing*. 1996; 10(4): 289-312
[3] French MJ. Conceptual Design for Engineers. The Design Council, 2nd, London. 1985: 1-50
[4] KIM Huichol, GUO Weizhong, WANG Yuxin, ZOU Huijun. Innovation of Behavior Structure Grouping Based On Genetic Algorithm. *Chinese Journal of Mechanical Engineering.* 2007; 43(5): 24-28.
[5] ZHANG Guang-Jun, TANG Dun-Bing. Research on Integration of Axiomatic Design Matrix and Design Structure Matrix. *Machine Design and Research*. 2008; 24(5): 1-6.
[6] Feng Peien, Zhang Shuai, Pan Shuangxia, Chen Yong, He Bin. Cyclic Solving Process and Realization For Conceptual Design Of Complex Function Product. *Chinesejournal of Mechanical Engineering*.
[7] MS Erden, H Komoto, TJ van Beek, V D'Amelio, et al. A review of function modeling: Approaches and applications. Artificial Intelligence for Engineering Design. *Analysis and Manufacturing*. 2008; 22: 147-169.
[8] Kitamura, Yoshinobu, Sano, Toshinobu, et al. A functional concept ontology and its application to automatic identification of functional structures. *Advanced Engineering Informatics*. 2004; 16(2): 145-163.
[9] DG Individual Based Models and Dangles L, Louis J Approaches in Ecology. New York, USA: Chapman&Hall. 1992.
[10] Johns Gero, Udokannengiesser. Afunction behavior structure ontology of process. Artificial Intelligence for Engineering Design. *Analysis and Manufacturing.* 2007; 21: 379-404.
[11] Kitamura, Yoshinobu, Mizoguchi, Riichiro. Ontology-Based Functional-Knowledge Modeling Methodology and Its Deployment. *Engineering Knowledge in the Age of the Semantic Web*. 2004; 21: 99-115.
[12] Kitamura Y, Mizoguchi RO. Ontology-based description of functionaldesign knowledge and its use in a functional way server. *Expert Systems with Applications*. 2003; 24: 153–166.
[13] Hao Yongtao, Ma Chong. Research of Product Function Gene Model Based on Behavior Semantic Web. INC, IMS and IDC. NCM '09. *Fifth International Joint Conference*. 2009: 622.
[14] Gunawan B, Rivai M, Juwono H. Characterization of Polymeric Chemiresistors for Gas Sensor. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(2): 275-280.
[15] YE Yang, CH ENG Shao, et al. Modeling and Analyzing of Train Operation Systems Based on a Kind of Hybrid Petri Net. *Journal of the China Raii Way* Society. 2009; 31(5): 42-49.
[16] Yongtao Hao. Research on auto-reasoning process planning using a knowledge based semantic net. *Knowledge Based System.* 2006; 19(8); 755-764.
[17] Lefebvre, C Delherm, E Leclercq, F Druaux. Some contributions with Petri nets for the modeling. *Analysis and Control of HDS*. 2007; (04): 66-78.
[18] Hao Yongtao, Ma Chong. *Research of Product Function Gene Model Based on Behavior Semantic Web. INC, IMS and IDC*. NCM '09. Fifth International Joint Conference. 2009: 622.
[19] Hong X, Liang G, Kaiwei W. Dynamic characteristics analysis of mats of ballasted track on bridge. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(7): 1779-1784.