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Improvement of product design process by knowledge value analysis

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Abstract Nowadays, design activities remain the core issue for global product development. As knowledge is more and more integrated, effective analysis of knowledge value becomes very useful for the improvement of product design processes. This paper aims at proposing a framework of knowledge value analysis in the context of product design process. By theoretical analysis and case study, the paper illustrates how knowledge value can be calculated and how the results can help the improvement of product design process, such as deciding which knowledge to choose and what to do next.

1.1 Introduction

In this world of globalization, more and more enterprises consider knowledge management (KM) process as an important part, if not the only part, of their production activities (Nonaka and Takeuchi, 1995; Bernard and Tichkiewitch, 2008). Meanwhile, how to pay deeper attention to the crucial competence "knowledge" is becoming a strategic approach in production management, and product design process is linked more and more tightly with knowledge (Perry *et al.*, 2011).

When considering knowledge management in product design activities, how to evaluate knowledge has always been a challenging problem. Which knowledge is more "useful" and thus can add more value to the product? What knowledge to be acquired in the next step of design? The answers of such questions may greatly improve design activities, so the following sections will focuses on this related issue: how to calculate and analyze knowledge value in product design processes and help them improve.

1.2 How to evaluate knowledge value

1.2.1 Product development process

We may describe the product development process as the following procedure: a product starts from its initial state and arrive to a required state (final state), and a task T is supposed to be accomplished to realize this product evolution from that initial state P_0 to the final state P_n. The product development process can be described by a series of state changes. Given an initial state P_0, the product development process can be characterized by a sequence of product states « $P_0 \rightarrow P_1 \rightarrow P_2 \rightarrow \cdots \rightarrow P_n$ », where P_1 is the product state when t_1 is accomplished, P_2 is the product state when t_2 is accomplished, etc., and when task T is accomplished, the product comes to its final state P_n.

Task T can be defined as follow.

Definition 1. Task T is represented by a weighted directed graph $G(T) = (H, A, \Omega)$, where:

- H is a set of tasks, whose elements are the task T, the non-atom tasks t_m and the atom-tasks at_n, i.e., $H = \{h_i\} = \{T, t_1, t_2, ..., t_m, at_1, at_2, ..., at_n\}$;
- A is a set of directed arcs α_{pq}, i.e. h_p and h_q are linked by α_{pq}, from h_p to h_q ;
- Ω is a set of weights ω_{pq} which are assigned to each arc α_{pq}.

Particularly, the sub-tasks which do not have successors are named atom-tasks, noted as at_i.

The reason that T is characterized by a graph, not a tree, is that there may be several sub-tasks which are not independent and they may have one or several sub-tasks in common.

1.2.2 Knowledge value

Supposing that knowledge K is necessary to accomplish the task T and knowledge fragment k_i is needed to accomplish sub-task t_i, thus, k_i is the solution for the sub-task t_i, and knowledge K can be considered as a set of solutions which together can accomplish the task T. Obviously, a knowledge fragment k_i can be a person, a book, a plan or any type of solutions provided, and knowledge characterization in detail can be referred from the works of Xu and Bernard (2010a).

Based on this proposal, some questions may be raised. Is knowledge K can accomplish the task T completely? If knowledge K can only solve a part of the task T, which part is solved? What knowledge fragments k_i have to be added in order to solve the remaining parts? How to choose the knowledge fragments k_i to accomplish the unsolved sub-tasks?

In order to answer these questions, some hypotheses are firstly presented:

Hypothesis 1. The atom-tasks are noted as at_i, and all atom-tasks correspond to an explicit answer “yes” or “no” which shows whether it can be solved or not. In other words, the atom-tasks cannot be solved partially.

Hypothesis 2. The principles of task decomposition are as follows.

If the task T is decomposed into T_1, T_2, ..., T_n, we have:

a. $T \subset (T_1 \cup T_2 \cup ... \cup T_n)$

(The combination of the sub-tasks should cover the original task T)

b. $T \not\subset T_i$

(Any sub-task T_i cannot cover the original task T)

c. The task T is decomposed with weights, noted as:

$$T : \omega_1 T_1 + \omega_2 T_2 + ... + \omega_n T_n \text{, and } \sum_{i=1}^{n} \omega_i = 1.$$

(The weights indicate the importance of the sub-tasks to the original task, for example, if the design of a car focuses more on speed improvement, then the sub-task of speed improvement will have a higher weight than the sub-task of cost diminution)

The value of knowledge K_i to the task T_i is noted as $V(T_i, K_i)$. This notation indicates that knowledge is always in context, in other words, knowledge evaluation is linked with specific tasks. Knowledge value thus varies according to different tasks. For example, given a same knowledge fragment "to adjust the height of a chair", it could have a high value to the task "to consider the ergonomics" and have a low value to the task "to control the cost". The value of knowledge K to the atom-task at_i is defined as follows.

Definition 2. $V(at_i, K) = \begin{cases} 1, & at_i \text{ can be solved by } K \\ 0, & at_i \text{ can not be solved by } K \end{cases}$

Based on the two hypotheses and Definition 2, knowledge value can be measured by the procedure as follow.

Procedure for knowledge value measurement:

Step 1: All the value of knowledge K to the atom-tasks is obtained according to Definition 2.

Step 2: For any $h_i \in H$, find all the (h_i, h_j) and their associate ω_{ij} , then:

$$V(h_i, K) = \sum_j \omega_{ij} \cdot V(h_j, K)$$

The procedure shows that from Step 1 we can obtain all the $V(at_i, K)$ and from Step 2 we can obtain $V(T, K)$. When $V(T, K) \neq 1$, it means there are one or several sub-tasks which are not accomplished, so additional knowledge is necessary to make $V(T, K) = 1$. During this process of knowledge addition, both explicit knowledge and tacit knowledge might be needed. Usually, explicit knowledge comes from databases, publications, rules, etc. and tacit knowledge comes from experience, expertise, wisdom, judgment, etc.

If K_i can solve at_i and at_i is linked to T by a sequence of arcs with weights of ω_1 , ω_2 , ..., ω_m , then

$$V(T, K_i) = \prod_{u=1}^{m} \omega_u \cdot V(at_i, K_i) = \omega_{at_i} \cdot V(at_i, K_i)$$

This calculation process is realized by a calculator called CAL-KNOW, which is used in case study introduced latter.

If two knowledge fragment K_1 and K_2 are both available, $V(T, K_1)$ and $V(T, K_2)$ can be calculated and compared. Generally, knowledge that has a higher value is usually chosen. As collaborative networks is regarded as a critical success factor to achieve product innovation (Perry *et al.*, 2010), it is always useful to choose the most valuable knowledge to be exchanged and shared.

1.3 Knowledge evaluation in product design process

During product lifecycle design, which can be defined as a sequence of tasks (Nacsa *et al.*, 2005), both tacit and explicit knowledge may be required to accomplish the tasks at_i , so these two kinds of knowledge can add value to the knowledge of design K and thus make knowledge evolution (Bernard and Xu, 2009; Xu and Bernard, 2010b).

Here are the main steps to take during the procedure of knowledge evaluation in supporting product design.

1. To decompose of the product development process into simpler processes, in other words, to realize the decomposition of the task T into atom-tasks at_i .
2. To evaluate the value of the existing knowledge using the evaluation model introduced in the previous section.
3. If not all the atom-tasks are solved, find out which at_i should be solved next.
4. To add appropriate knowledge, explicit and/or tacit, to accomplish at_i .
5. Do Step 3 and Step 4 repeatedly until all atom-tasks are solved.

In the product design process, knowledge mat add value to products and product may also make knowledge more valuable (Xu and Bernard, 2011), and such mutual value adding process can be explicitly describe and controlled using our knowledge evaluation model.

1.3 Case Study

This paper has chosen a case of chair design, which is a part extracted from the product lifecycle of a chair. The concentration is implemented on the phase of design as it is a key phase where major decisions are made concerning knowledge. In this example, the task « design a chair » should be accomplished in order to make the product (chair) evolves in the development process. Figure 1(1) and Figure 1(2) illustrate how the task is decomposed. Although the decomposition is lack of completeness, for example, several tasks such as market study, packaging and logistics matters, particular optimization, etc., are neglected, it can serve as an adequate demonstration.

Based on the criteria obtained from experience in product design, the principle task « design a chair » is decomposed into four sub-tasks.

The weights ω_i are given by the experts of different roles who have different points of view in design activities. Table 1 shows the weights given to each sub-task by experts of different roles. In order to determine a weight, we have taken into account the results given by a group of experts for each given role. How to improve the results of collecting and analyzing the weight values given by different people is another complicated topic, which needs further researches on statistical techniques, human behaviors, etc., and in this paper, we simply regard the weight value as is the average of the weights proposed by all the experts assigned in each group.

Table 1.1 The values of weights

Experts of different roles	ω_A Comfort/aesthetics	ω_B Dimension/Mechanics	ω_C Costs	ω_D End of life
Client	50%	10	30%	10%
Designer	10%	50%	30%	10%
Manufacturer	0	30%	50%	20%
Seller	30%	10%	40%	20%
Transporter	0	60%	30%	10%
Recycler	0	0	30%	70%

Here are some illustrations about Figure 1.1:

- « Perception test » and « To consider the psychological comfort issues » can be solved by questionnaire surveys.
- « Ergonomic studies » mainly focus on examining the degree of fatigue of different parts of the body (muscle, bone, joint, etc.) of a person who sits in the chair for a period of time or by simulations.
- « Tests of the material attributes » may include the thermal conductivity (in winter, people do not like to sit in a chair with a surface of iron, because it's too cold), the sensation of the material (for example, smooth or rough, soft or hard), etc.
- « To consider the aesthetics of the chair » considers the intrinsic beauty of the chair, which depends on the cultural and social context. In other words, for a same chair, it may vary from beautiful to disgusting due to different tastes of people from different countries or groups.

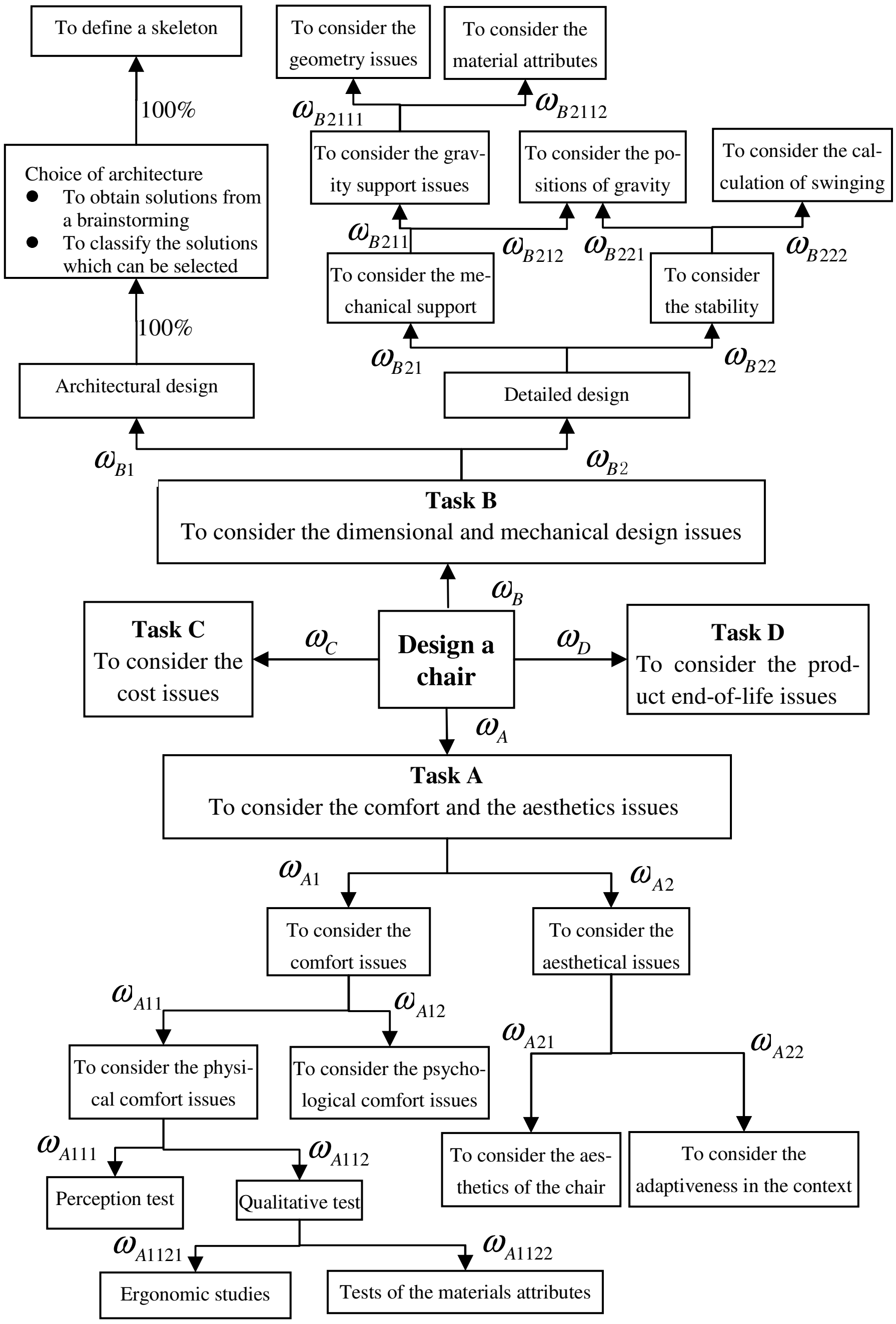

Fig. 1.1(1) The decomposition of the task « design a chair » (Part I)

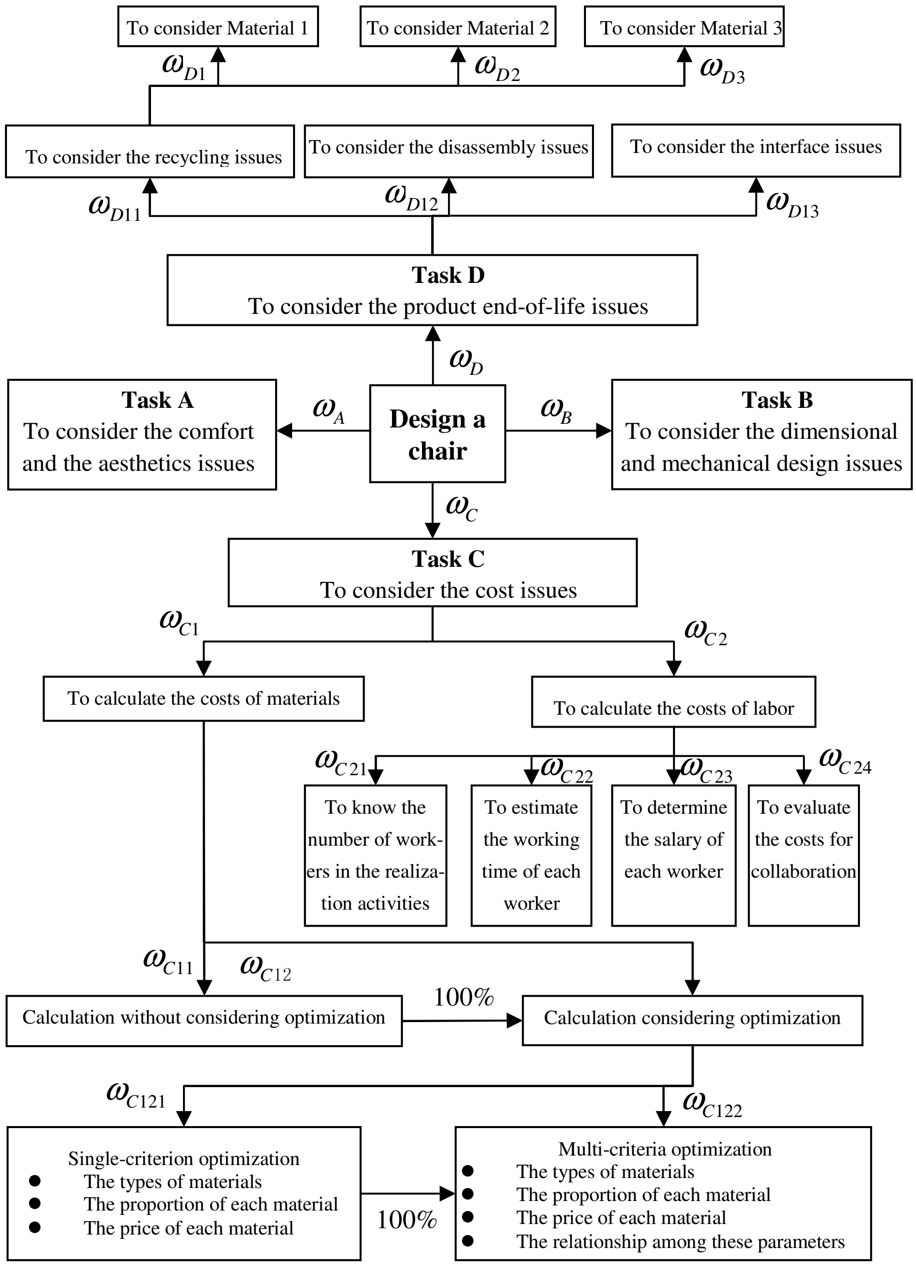

Fig. 1.1(2) The decomposition of the task « design a chair » (Part II)

- « To consider the adaptiveness in the context of use » considers whether the chair matches the environment of use. For example, in a fast-food restaurant, sofas are not suitable to the environment although they are very beautiful.
- « Architectural design » is considered before the design in details.
- For the assignments of the values of the weights ω_{B1} and ω_{B2}, they depend on whether the designer take optimization into account. Table 2 shows two examples in determining ω_{B1} and ω_{B2}. In an extreme situation, when a designer assigns ω_{B1} =100%, it means the designer will simply look for a solution in a database of archived designs.

Table 1.2 The values of the weights ω_{B1} and ω_{B2}

	ω_{B1}	ω_{B2}
If the designer pay much attention in optimization issues during the design process	30%	70%
If the designer do not wish to spend too much time in searching for optimization solutions for Task B	50%	50%

- The tasks « To consider the mechanical holding issues » and « To consider the stability » have a same sub-task « To consider the positions of gravity centers ». Such situation that several tasks may have a same sub-task in common is acceptable according to Definition 1 which defined the Task T as a graph.
- Here are two weights which have the value « 100% ». They mean that the tasks linked by an arrow of a weight of « 100% » are « equal ». In this case, when people have accomplished « to define a skeleton », they have accomplished the « architectural design » at the same time.
- In order to determine the values of the weights ω_{C1} and ω_{C2}, the context of design should be considered, in other words, they depend on the amount of production of the chairs provided by customers. Table 3 gives two examples. In the condition that the chair is designed to be produced in large quantities, the cost of materials has a weight of greater importance. When it is a case of custom design, the weight of materials is lower. The client is willing to pay the extra cost for differentiation even if the materials used are more expensive.

Table 1.3 The values of the weights ω_{C1} and ω_{C2}

	ω_{C1}	ω_{C2}
If the chair is designed to be produced in large quantities	80%	20%
If the chair need a custom design with a small amount of production expectation	20%	80%

- If several tasks have the relations of inclusion, an arrow with a weight of "100%" is used. Design optimizations are often made retrospectively by taking into account new knowledge (Chenouard, 2007)
- Why the arrow from the task “Single-criterion optimization” to the task “Multi-criteria optimization” has a weight of “100%”? Obviously, when people can perform the task of “Multi-criteria optimization”, they are able to accomplish the task of “Single-criterion optimization”. In other words, these two tasks have a containment relationship. In case when two tasks have a containment relationship, an arrow of a weight of “100%” is used. Optimizations of the design are often made retrospectively, taking new knowledge into account, (Del Prete *et al.*, 2010).
- Management of product end-of-life and recycling are critical issues in environment treatment for manufacturing enterprises so they should be considered in product lifecycle design (Bufardi *et al.*, 2003; Ueda *et al.*, 2005). The task « To consider the recycling issues» needs knowledge about the possibilities of recycling the materials used.
- The number of materials to be considered is not limited to three, and it may differ from case to case. In other words, this number depends on how many principal types of materials are used to build the chair.
- The three weights ω_{D11}, ω_{D12} and ω_{D13} are determined by several factors of the chair, for example, the proportion of each material used, the cost of each material used, etc.
- The task « To consider the disassembly issues » evaluate whether the designed chair can be disassembled. The easy disassembly of a product will facilitate the recycling of material used and the reuse of different parts of the chair.
- The task « To consider the interface issues » mainly considers the reuse issues of different parts of the chair. For example, if a chair has a leg broken, instead of throw away the chair and replace it by a new one, people can simply substitute the broken leg. But in order to realize the substitution of the

broken leg, the interface between the leg and the body of the chair should be well designed. In such cases, the design of the interface should be given special attentions.

In real cases tested, each time a solution (knowledge fragment) with a higher value is chosen, and from the list of unaccomplished atom-tasks, we could find out easily which tasks should be accomplished next. Every time that *K* reaches a state that can solve one more task, its value increases.

When knowledge reaches its final state, its value may not always be 100%, but it is not critical if people are already satisfied with its current value. In the given example, if we do not have to accomplish the task of "To calculate the cost of labor", knowledge can remain in a state that its value is not 100%. In such cases, people have to take some risks when they are going to the next stage of the product lifecycle.

1.4 Conclusions

Knowledge evaluation is a key issue in knowledge management, and this paper has presented a knowledge evaluation model in product lifecycle design. The model integrates the process of knowledge evolution and product development, and the mutual effects between knowledge and product are analyzed. Based on the theoretical definitions and models, this paper illustrates how knowledge value can be assessed by studying a specific case. In the applications of product lifecycle design, knowledge values calculated by the model can serve as important factors in a decision making system that decides which knowledge to choose and what to do next. The model could serve as a framework to describe the knowledge related activities and could be a useful tool for managing knowledge in product lifecycle design and support.

Interesting perspectives may include deeper analysis about the optimization issues of weights and dynamic product development processes.

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