Title:
Product Innovation Design Based on Scenario and LT Dimensions

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Introduction:

Scenarios mainly embody an explicit description of the hypothetical action process of a product at some stage of its life cycle. The innovation arises from the transformation of conceptual spaces or the mapping of different knowledge systems, with the core being the transformation of knowledge from one scenario to another. Kurakawa[4] proposed a process to assist product conceptual design by discussing scenarios of future product applications through meetings. Liu et al. [6] proposed a method for expressing and inferring future elements in scenarios and innovatively designed them by analogizing effect cases into scenario units. Some studies integrate scenarios with other methodological tools for solving product innovation design scenarios or for technology foresight. Lee et al. [5] adopted an approach using Cross-Impact Analysis (CIA) and Analytic Hierarchy Process (AHP) as a scenario-based roadmap tool. Hussain et al. [2] proposed a technology foresight approach by combining scenario planning and the technology roadmap method. Although the existing studies provide new ideas on using scenarios in the innovation design process, the theory still needs to be mature. There is a need for more methods to discover innovation opportunities based on scenarios and acquire valuable innovative knowledge based on imperfect situational conditions.

The effects can be quantified and expressed through the functional relationship between physical quantities. It has been proposed that two fundamental quantities, length L (length) and time T (time), can describe other physical quantities, and the relationship between the two dimensions of L and T has been established. The operation of the LT scale is critical to its auxiliary representation of relationships between physical quantities and intellectual reasoning. Rodenacker and Koller [3] compiled a compendium of physical effects to summarize the LT scale effects knowledge base, specifying the input and output scales of the effects to aid the effects knowledge search process Through the LT dimension as a bridge and the effect knowledge base, potential effects for achieving the required functions can be discovered, and the connection between product functions and the principles of implementing functions can be established to obtain valuable knowledge and cases.

This paper explores a new approach to introducing scenarios and LT Dimensions into product innovation design. First, construct new scenario conditions and incorporate them into the scenario behavior of the prototype product, and identify mismatched scenario units and critical points for product improvement. Then, the LT dimension is introduced into the effect search process, and a heuristic case-by-case search method is proposed by matching effect and scenario elements, which is used to obtain valuable innovative product design solutions adapted to new scenario conditions by analogy. The innovative design of the Chinese medicinal materials (CMMs) dispensing machine verifies the proposed method.

Main Idea:

This study proposes product innovation design based on scenario and LT dimensions, as shown in Fig. 1, which consists of four steps.

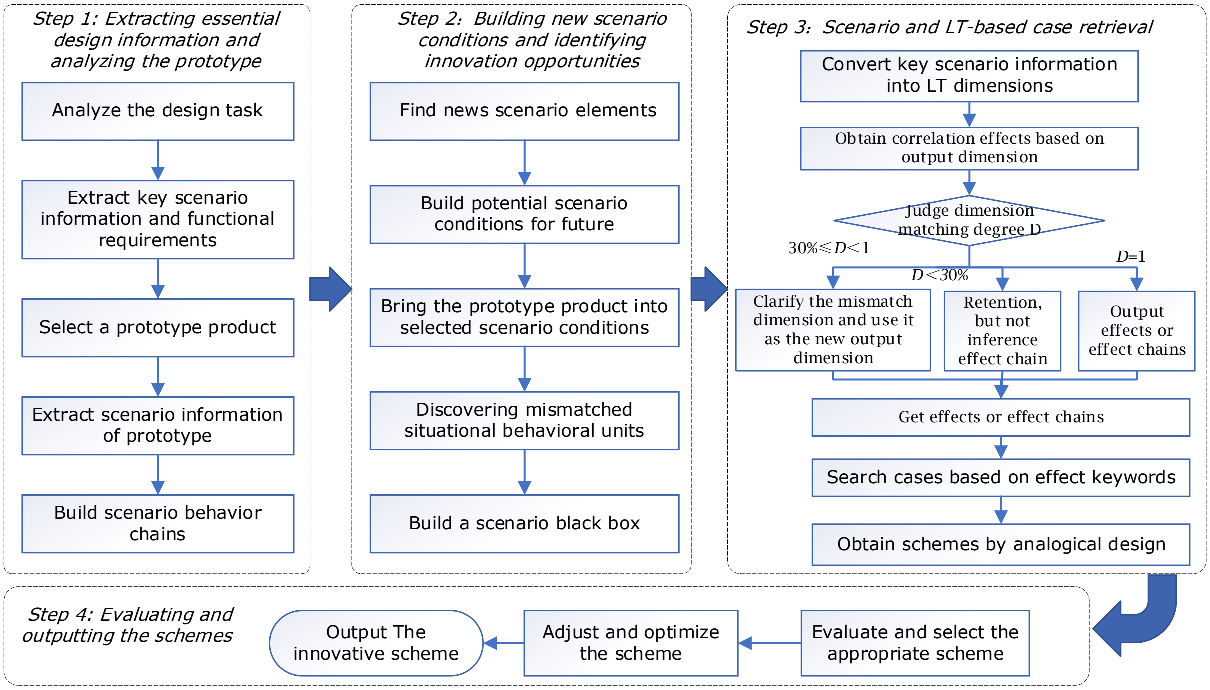

Fig. 1: Product innovation design process based on scenario and LT dimensions.

Step 1: Known scenario elements in the future product scenario are identified, usually including some essential initial and ending scenario elements. The dominant functional requirements and critical functional attributes can also be elucidated. Then, select a product that satisfies the design requirements to a certain extent as prototypes, extract typical scenario information, and construct scenario behavior chains that draw on the method of literature [6].

Step 2: Key scenario elements that may be present in future product scenarios can be obtained through scenario elements' directed divergent thinking from environment-related and user-related directions. In addition, the scenario variables should be reorganized to determine potential conditions for future scenarios. Prototypes are brought into selected new scenario conditions, unsupported scenario behavioral units are identified, and scenario black boxes are constructed.

Step 3: To make the search effects more targeted, trace the features back to the expected scenario unit, clarify its pre-order and post-order scenario elements as the expected input and output flows, and obtain available resources from the expected scenario. The input/output flow and the resources available to the system and supersystem are converted to LT dimensions as key physical quantities, then the effect black box is.

Then, the expected input and output dimensions are C_{IP} and C_{OP}, respectively. Since the output side of the effect black box is the physical quantity most needed to complete the scenario behavior, the appropriate effect/effect chain is gradually searched for, starting from the output side. Find the set of effects from the knowledge base of LT dimension effects whose LT dimension at the output side coincides with the C_{OP}.

For the obtained effect knowledge, if there exists n input dimension in the right-hand side of the equation corresponding to the effect, and m of the set of available dimensions in the system coincides with it (m ≤ n), the matching degree D is

$$D=\frac{m}{n}\times 100\% \tag{1}$$

If D=100%, it is consistent with the principle of dimension compatibility and can be directly used as potential effect knowledge; if D < 100%, it means that the existing resource condition is missing the element that provides a certain key dimension. For the effect knowledge with D< 100%, the effect inference is continued with the missing dimension of resource matching as output. After judging the obtained effect knowledge, stop if it is compatible, otherwise continue reasoning, and finally, the effect chain can be derived, as shown in Fig. 2. Where C_{i1}, C_{i2}, C_{i3}, C_{i4}, and C_{ik} are all the available resources in the existing dimension, and C_{in} is the mismatch dimension for the secondary effect inference.

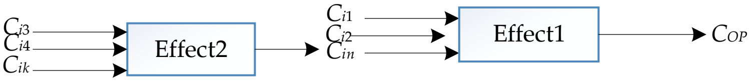

Fig. 2: Effect chain based on LT dimension reasoning.

After selecting the appropriate effect chain, the relevant case needs to be searched. The effect or effect chain needs to be converted into common key behaviors, expressions, institutions, etc. Keywords for effects can be converted into a series of functionally relevant verbs based on the behavior of the case application. Based on the keywords to construct for patents or related product searching. In the analogous design, it is necessary to replace or add relevant structures to the associated behaviors and adjust them according to the mechanics. After retrieving the cases, the structure of the new scenario behavior required for its implementation can be extracted. Then, a suitable case as an analogous source can be selected by considering factors such as complexity, matching, improvement difficulty, cost, and more.

Step 4: To optimize and select the appropriate innovation scheme can be introduced the evaluation of key indicators of each scheme by experts.

Case Study:

The proposed method is applied in Chinese medicinal materials (CMMs) dispensing equipment.

1) After analyzing the product design task, the dominant demand is "dispensing CMMs"; the main body of the scenario element is "CMMs." The prototype product shown in Fig. 3 relies on the flipping roller and gravity to make the CMMs fall through the weighing platform to calculate the amount of CMMs, and feedback control sealing plate to determine the opening and closing of the CMMs.

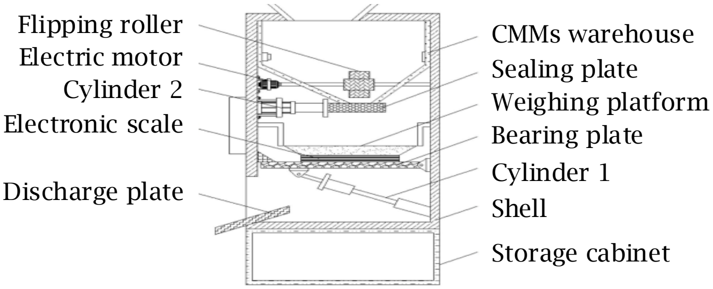

Fig. 3: A gravity type CMMs dispensing equipment.

The typical action place of the prototype product is indoors, such as in pharmacies, hospitals, etc. In the expected scenario evolution, the initial scenario conditions include P0Eci= [CMMs, physical shape, small and regular granules], P0Ee1= [indoor, state, normal temperature and pressure], P0Ee2= [socket, state, presence of electricity], P0Eu1= [users, characteristics, the able-bodied]. The core scenario element of the ending state is P0Ece= [CMMs, state, quantitatively stored in one bag]. The scenario behavior chain of the prototype product can be built.

2) Some new scenario variables can be set, and multiple new scenario conditions can be reconstructed. the powder or granular CMMs can be quantitatively configured several times in succession with electric power in hospitals is selected for further design. However, the prototype product could not fulfill the scenario variables S1= [CMMs, physical shape, granules, and powder] due to its inability to perform the configuration of powdered CMMs, and S2= [CMMs, status, quantitative continuous multiple bags] cannot be met by prototype product. These are the two types of innovation opportunities captured through the scenarios.

S_1 was brought into the scenario behavior process of the prototype product, the strong relevant scenario behavior unit of S_1 is "export CMMs".

3) The key function action of "export CMMs" can be abstracted as "move solid", there are also air, gravity, electricity, rotary power, and other resources in the scenario. The pre-order scenario elements are [CMMs, location, medicine box], [energy, type, kinetic energy, and electric energy], and the post-order scenario elements are [CMMs, state, falling], [energy, type, kinetic energy, and electric energy]. There are also air, pressure, gravity, electricity, rotary power, and other resources in the scenario.

After analysis, the key flow is CMMs, and it is found that the physical quantity corresponding to the dominant characteristics is distance *d*, velocity *v* and force *F* with LT dimension L^1T^0, L^1T^{-1}, L^4T^{-4} . Then other possible resources can be transformed to LT dimensions. An effect black box can be constructed as shown in Fig. 4.

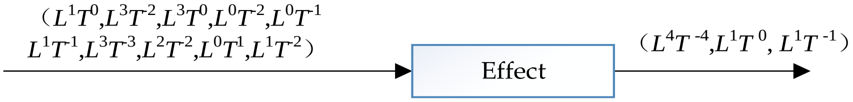

Fig. 4: Effect black box.

An effect search is performed based on the input and output dimensions, and a matching effect set is obtained based on the LT dimension effect base [3]. as shown in Tab. 1.

Tab. 1: A set of effects consistent with L^4T^{-4}, L^1T^0 and L^1T^{-1}

Effect Name	Formula	Input physical quantity	Output physical quantity	Input LT dimension	Output LT dimension
Barometric effect	$F=P\cdot S$	P, S	F	L^2T^{-4}, L^2T^0	L^4T^{-4}
Centrifugal force effect	$F=m\cdot w^2\cdot r$	m, w, r	F	L^3T^{-2}, L^0T^{-1}, L^1T^0	L^4T^{-4}
Magnetic attraction effect	$F=H\cdot Q$	H, Q	F	L^3T^{-2}, L^2T^{-1}	L^4T^{-4}
Movement Principle	$L=v\cdot t$	v , t	L	L^1T^{-1}, L^0T^1	L^1T^0
Archimedes' spiral effect	$r=a+b\cdot\theta$	b	r	L^1T^0	L^1T^0

It is found that most of the above effects have a D=100%, the barometric effect has D = 50%, since 30% < 50% < 1, the inference of the effect chain can be carried out. The mismatched physical quantity is pressure P with LT dimension L^2T^{-4}, a set of effects can be got. Barometric effect, Pascal effect, Coanda effect, and Venturi effect can be found to have D=100%, so they can all form a new effect chain with the barometric effect, and the number of inferences is 1, which meets the inference rule, as shown in Fig. 5(a), Fig. 5(b), and Fig.5(c), respectively.

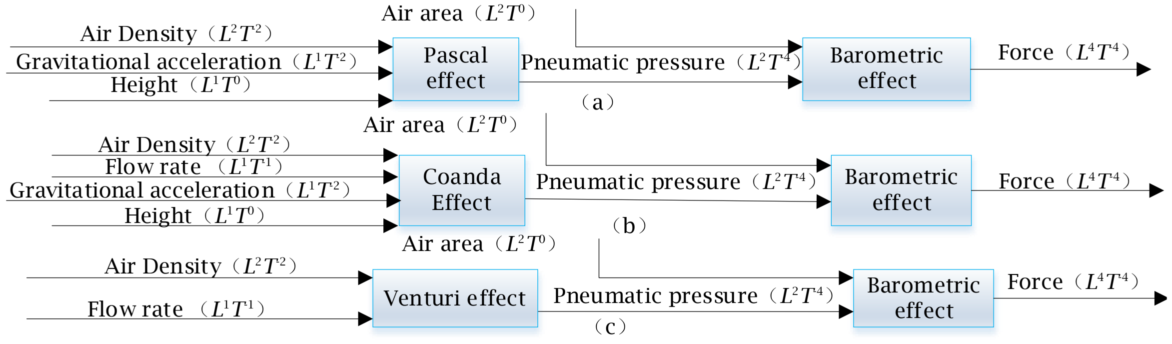

Fig. 5: Effect chains.

"Air suction" can be extracted as the key word from the Venturi effect and Barometric effect, the main function can be abstract as "move object". Then, using ("air suction" and "move object") as the retrieval formulas for patent retrieval, over 100 related patents were searched, a suitable case called "A negative pressure automatic feeding device" is selected as shown in Fig. 6(a), then an innovation scheme 1 is got through analogy improvement as shown in Fig. 6(b). Similarly, by selecting Archimedes' spiral effect, scheme 2 can be obtained as shown in Fig. 7.

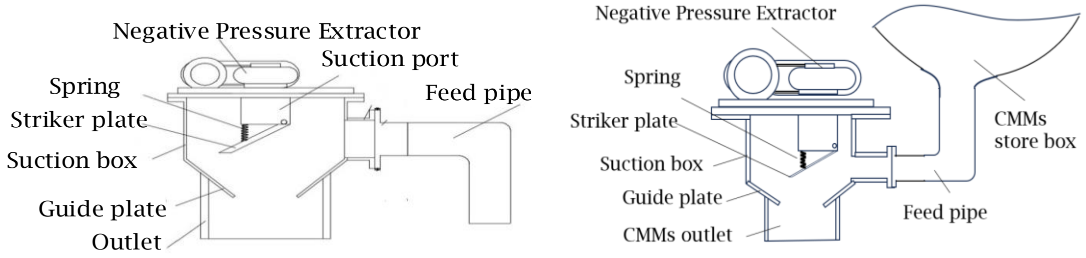

Fig. 6: (a) A negative pressure automatic feeding device, (b) Schematic diagram of the negative pressure type CMMs transport mechanism.

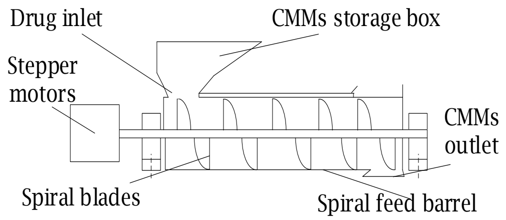

Fig. 7: Schematic diagram of the screw feeding type CMMs transport mechanism

4) After the expert analysis, the new schemes are evaluated with speed, accuracy, reliability, novelty, applicability and cost as the evaluation indexes, and the result shows that Scheme 2 is more excellent. In the same way, an innovative scheme design of a continuous weighing and collecting device is obtained, as shown in Fig. 8.

A new CMMs dispensing machine can be obtained by integrating and optimizing the schemes as shown in Fig. 8. The experiment shows that the new scheme can realize design requirement, and the output speed and accuracy are better than the prototype product.

Ten experts compared our method with existing methods regarding the applicability, complexity, learning difficulty, and efficiency of high-quality scheme outputs. The proposed method has certain advantages in applicability, innovation efficiency, and other aspects compared to traditional innovative design methods.

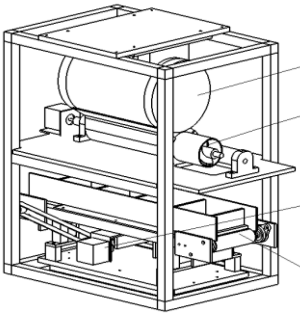

Fig. 8: An innovative CMMs dispensing equipment.

Conclusions:

This paper explores a new direction of introducing scenario and LT dimensions into innovative design. By constructing new scenario conditions and incorporating them into the scenario behavior of the prototype product, identify mismatched scenario units and key points for product improvement. Then a heuristic case search method based on LT dimension effect retrieval method and scenario element matching is introduced, which is used to guide designers in acquiring valuable innovative product design schemes through analogy. Further work will apply the method to different cases.

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