Application of Technology-Effict Matrix and TRIZ In Innovative Design of Rotary Cultivator

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Abstract. In the process of technological evolution of products, some functions may evolve slowly, which hinders the evolution of products as a whole. In order to compensate for the imbalance of technological evolution and find the corresponding technical shortcomings, a product design process combining technology-effect matrix with TRIZ is proposed. Through searching and screening patents related, the target patent pool is obtained and each patent is labeled. We, at the same time, summarize the technical means and effects, construct the technology-effect matrix and deduce the design objectives by extracting the technical weaknesses. Finally, the design model is obtained through using TRIZ tool to analyze the design objectives. Taking the innovative design of rotary cultivator as an example, the technology-effect matrix of rotary cultivator was constructed and a technical weakness was extracted. Based on this, the innovative design of rotary cultivator was carried out with the objective of reducing the wear of rotary cultivator blade, and thus the feasibility of the design process was verified.

Keywords: Industrial design, rotary cultivator, technology-effect matrix, TRIZ, evolution of technology.

1. Introduction
With the development of technology, products are constantly updated with increasingly abundant functions. However, in the technology progress, the imbalance may occur in the function development. TRIZ believes that there are certain regular patterns in product evolution, among which the imbalance would lead to conflicts [1]. Therefore, how to expose the weakness of technology and provide services for innovative design has become the key to make up for the weakness. As a tool for patent qualitative analysis, technology-effect matrix can visually process complex patent information and mine out the hot and weak points of patent in technology [2]. Through empirical analysis on endoscopes, Xu Haiyun [3] and other researchers demonstrated the characteristics, advantages and disadvantages of patent technology-effect theme words and patent citation in patent mining; Zhang Xin [4] and Wang Xin [5] combined technology-effect matrix with TRIZ evolution theory to guide product design and product evolution direction. Hence, the technology-effect matrix can not only be used to mine weaknesses in technology evolution, but also to guide product innovation design. In this paper, with the product design processes of both technology-effect matrix and TRIZ applied and the rotary cultivator used as the design example, a technology-effect matrix is constructed to extract the technical weakness to
deduce the design objective. On the basis that technical repetition is avoided, the success rate in product innovation is improved. The TRIZ tool is used to obtain the design objective and then the design scheme, so that the weakness that appears in the technology evolution process can be made up for.

2. Construction of Technology-effect Matrix

The technology-effect matrix can process and integrate a large number of scattered patent information and transform it into competitive intelligence that can be used to overview the overall situation and predict the development of technology. It is a tool for in-depth analysis on the patent technology [2]. Through the matrix, the degree of aggregation and evacuation of patent applications in a certain technology can be figured out. The technology with relatively concentrated applications can be identified as a hot point, and the technology with relatively scattered applications can be determined as a weakness. With the help of literature recorded in patent, a technology-effect matrix can be constructed to effectively mine potential technology information and extract hot and weak points in technology, providing reliable information for enterprises in technological innovation and strategic layout.

2.1. Patent Retrieval and Screening

The rich and detailed technical information in patent literature is particularly important for designers to carry out research and development and for enterprises to formulate strategies [6]. As an important step before the construction of technology-effect matrix, patent retrieval and screening play an important role in collecting patent information and avoiding repetitive research. A good performance of the retrieval and screening becomes an important guarantee for guiding innovative design. Patent screening is a complex and tedious work, so it is necessary to set up an appropriate search formula to obtain key patent information, so as to improve the retrieval accuracy of patent in need. The commonly used patent retrieval and screening methods include international patent classification (IPC) [7], keyword combination [8], product life cycle curve [9] and fast reading and screening.

- IPC is the only internationally accepted tool for patent document classification and retrieval. The classification numbers of both invention patents and utility model patents are marked in IPC form. Through IPC, patents can be screened in terms of the applications and functions, so as to retrieve the patent information in the technology field that the products belong to.

- In patent screening, keyword retrieval plays a role in determining the technology scope of the final target sample library. Through retrieval combining one or more keywords, the target technology is framed within the scope of research objectives, and the samples are further screened.

- The product life cycle curve, also known as the S-shaped curve, can divide the life cycle of a technology into four stages, namely: infancy, growth, maturity and exit. Enterprises can carry out R & D investment and layout according to the different stages, and the technology in mature and mature stages is the most suitable for innovative design [10].

- Through the combination of IPC and keyword screening, the sampled patents can be screened into a certainly precise range, but there are still some noise patents in the result which have no impact on the research objectives and repeatability. In order to improve the accuracy of the final sample library, fast reading can be used to eliminate the noise ones to determine the final library, so as to save time for following construction of the technology-effect matrix.

2.2. The Extraction and Summarization of Technical Means and Effects

Technical means correspond to technical words and technology-effects correspond to effect words in patent documentation. As the words presenting the core technology in patent documentation, technical words reveal the solution to the design issue, which is the key exposition reflecting the core technology of the enterprise: Effect words are the effect achieved after solving the problem in patent documentation, it is the objective of patent research, and is also the design requirements that the designer hopes to achieve. The extraction and summarization of technical words and effect words from patent documentation in the sample pool generally go through the following processes:
• Documentation pre-processing. By carefully reading patents in the sample pool, label and make statistics of the technical means categories and technology-effect categories shown in the documentation. Too many categories, however, dilute the embodiment of patent’s implicit message and reduce the mining value of technology-effect matrix. Therefore, it is necessary to further summarize and handle various kinds of technical means and technology-effects.

• Consensual treatment. As the patent kinds are many, the same technology-effects can be realized with different technical means. Also, the similar technical means and effects will be emerged. Or the expression modes of the same kind of technical means or effects are not the same in different patents. So, the consensual treatment is required artificially by combining the same technologies or similar technologies to get technical word categories and effect word categories.

• Statistics and evaluation. Evaluate the determined technical words and effect words, modify the words whose semantics are not suitable, and finally generate the technical word categories and effect word categories. Make statistics of the corresponding patent numbers to be presented with technology-effect matrix by means of visualization.

2.3. Technology-Effect Matrix

The x-coordinate with effect words as the matrix and the y-coordinate with technical words as the matrix, and make statistics of the corresponding patent numbers to be filled into the intersection of the x and y coordinate to construct the technology-effect matrix. In order to enhance the visualization, bubble chart is often used to show, whilst the number of patents translates into the size of the bubble. The technology distribution can be better reflected by the form of bubble chart.

Tracking technology hot spots can help to understand the status of existing technology development; grasp the “technical minefields” and “technical barriers”. Meanwhile the avoidance of technical hot spots can effectively avoid the infringement caused by technology duplication in the process of product technology development; the technology hot spots are the area where the patent technologies are gathered massively. From the perspective of product evolution, the product in this technology is approaching saturation, reaching the ideal state. So, product design starting from technical hot spot will cause too much difficulty in innovation.

As to technical weakness, it is the technology-effect that is less thought of in the process of product evolution but still exists in the actual process of product evolution. It becomes the technical shortcoming affecting the overall evolution of the product due to its less attention. Through the analysis to the technical weaknesses, the “technical minefield” can be effectively avoided. The innovative design to the design objective counter inferred to it compensates the imbalance of its functions, and improves the success rate of product innovation while avoids repetition in technology.

3. Design Flow of the Product Innovation with Technology-Effect Matrix and TRIZ

The design objective is obtained by counter inference of the extraction of technical weaknesses based on technology-effect matrix. The thought of changing the tradition so as to analyze user’s demands and start the hot spot technology to conduct innovative design, based on patent documentations, technical shortcomings which are focused less in technology evolution is discovered can effectively compensate the imbalance in technological evolution of the product by innovative design to them, meanwhile maximally reduce the repetition in technology. The success rate of product innovation is improved while avoiding technology infringement. The innovative design is guided by introducing TRIZ tool [11], which even accelerates the design circle and shortens the innovation time, satisfying enterprise’s higher demands to designers. The technology-effect matrix is used to obtain the design objectives, and the TRIZ tool is used to solve the problem to obtain the design scheme, thus a complete product innovation design process is established, as shown in Fig. 1.
• Initial samples. The initial samples are formed by deciding research objects and the patent search is conducted for the first time through patent websites based on product names.

• Patent screening. The corresponding search strategies are formulated through IPC and key words to conduct the patent screening for the first time; the life cycle curve is generated to patents after screening according to application days and corresponding patent numbers and to decide the life cycle of research objectives and choose appropriate application time period; quickly read the remaining patents to eliminate patents which do not affect research objectives, thus the screening is conducted to the patent for the second time. Decide the screening accuracy to the highest level to form the final target patent pool.

• Extracting technical words and effect words. Read and index the patents in patent pool, prepare and make statistics of technical means and effect of each patent; conduct consensual treatment to similar technical means and effects respectively to decide the final technical word categories and effect word categories.

• Establishing technology-effect matrix. The patents in target patent pool are summarized into the corresponding matrix tables to establish technology-effect matrix bubble chart based on the data in the tables.

• Deciding design objectives. Summarize and analyze the technology hot spots and weaknesses of the technology-effect matrix. The development trend of current technologies is analyzed with technology hot spots, and technical weaknesses are analyzed with technical shortcomings. And the required design objectives are counter inferred by them.

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**Fig. 1 Design Flow of the Product Innovation with Technology-Effect Matrix and TRIZ.**
• Design scheme. Based on design objectives and through TRIZ analysis, it is converted to a general issue. The target solution is obtained through contradiction matrix and invention principles and it is converted to the design solution to get the design scheme.

• Infringement determination. The infringement determination of current technology is conducted to the design scheme. The innovative design of product is completed after no error of determination, so as to achieve design objectives.

4. Example of Innovative Design of Rotary Cultivator

As an important machinery in agricultural cultivation, the rotary cultivator can break up the clods and stubble ploughing to land before plantation and level land after plowing, which is conducive to strive for the farming season and improve the soil conditions [12]. According to the configuration of cutter shaft, the rotary cultivator can be divided into horizontal axis rotary cultivator and vertical axis rotary cultivator, where horizontal axis rotary cultivator is capable of breaking up strong clods, so that it is suitable for dry farming operation [13]. Hence the related patents of horizontal axis rotary cultivator are taken as examples to conduct the innovative design of rotary cultivator in this research.

4.1. Patent Searching and Screening of Rotary Cultivator

The Patentstar website(www.patentstar.cn) is taken as the search engine of searching patents and the patent name “rotary cultivator” is as the searching object, the first search of related patents is conducted to obtain 2252 patents including patent for invention, utility model and appearance patents. As the target numbers are too massive, the initial samples need to be screened.

• We have found by checking that the subclass of the belonged class number of rotary cultivators is A01B, and there are eighty percent patents in initial samples assembled in supergroups A01B 33 and A01B 49. Based on that, the less patents of the two supergroups of the appearance patent in initial samples (not including practical technical methods) are eliminated, the remaining is 1795 patents.

• The horizontal axis rotary cultivator is taken as the example in the research, the vertical axis rotary cultivator is not considered, and vertical axis is taken as key word to screen. The 16 patents containing vertical axis as key word in remaining patents are removed, and the remaining patent quantity is 1779.

• Extract the group subclasses in the two supergroups where the patents are in. The secondary screening is conducted to patents by choosing the group subclasses A01B33/00, A01B33/02, A01B33/08, A01B33/10, A01B33/12, A01B33/14, A01B33/16, A01B49/00, and A01B49/02 by definition, the remaining patents are 1668.

• As an important component of rotary cultivator, the rotary blade is an inevitable part of rotary cultivator. Screen the remaining patents by taking the key word “rotary blade”, 590 patents are left.

• Make statistics of the years of application days to the remaining patents to make the life cycle curve shown in Fig. 2. It is found that since 2008 rotary cultivator has increased dramatically, showing it is in its period of growth, which is most suitable for innovative design. Therefore, according to application days, a 10-year period patents are selected from 2008 to May 2018, to the remaining patents 486.
• Quickly read the remaining patents to remove patents of repetition, invention methods and not belonging to this research subject, where patents beyond research scope include small hand guided rotary cultivator and the power source of rotary cultivator, to obtain the final 241 target patent pool patents. The screening process of rotary cultivator is shown as Table I.

Tab. 1 Screening Process of Rotary Cultivator Patents

| Permission    | Searching Name                      | Remaining Patent Numbers |
|---------------|-------------------------------------|--------------------------|
| Patent name   | Rotary cultivator                   | 2252                     |
| Class number  | A01B33+A01B49                        | 1795                     |
| Key word      | Vertical                             | 1779                     |
| Class number  | A01B33/00+A01B33/02+A01B33/08+A01B33/10+A01B33/12+A01B33/14+A01B33/16+A01B49/00+A01B49/02 | 1668                     |
| Key word      | Rotary blade                         | 590                      |
| Application day | 2008/01/01—2018/05/01               | 486                      |
| Quick reading | Invention methods and inventions are rejected | 439                      |
| Quick reading | Repetition                           | 361                      |
| Quick reading | Beyond research objective scope      | 241                      |

4.2. Constructing Technology-Effect Matrix of Rotary Cultivator

By careful reading of the patent samples in target patent pool, the corresponding technology-effects and means are extracted and the consensual treatment is conducted to the similar meaning words. It is finally concluded 11 technology-effects and 18 technical means, shown in Fig. 3, so that the technology-effect matrix of rotary cultivator is constructed.
Through the analysis of technology-effect matrix of rotary cultivator, the following conclusions can be obtained:

- High efficiency of clods breaking up, land leveling after cultivation and deep ploughing have become the hot spot direction for modern rotary cultivator. As to compensating technical shortcomings of rotary cultivator so as to have innovative design to it, three patent assembling points can be avoided, preventing the excessively high innovation difficulty and work repetition.

- How to improve clods breaking up of rotary cultivator is paid too much attention but the protection of rotary blade is ignored, so that technical weaknesses occur in two technology-effects of reducing rotary blade wear and protection of cutter shaft, which also cause the imbalance of rotary cultivator in its product evolution process. A technical weakness was extracted. Based on this, the innovative design of rotary cultivator was carried out with the objective of “reducing the wear of rotary blade”.

**Fig. 3 Technology-Effect Matrix of Rotary Cultivator.**
cultivator blade“. It compensates the shortcomings of technology development while improving the success rate of innovation.

4.3. Innovation Design Scheme of Rotary Cultivator

With the design requirement of reducing rotary blade wear, the main factors of affecting rotary blade wear are analyzed. While rotary cultivator is working and in the process of rotary blade from its entering soil to unearthing, the resistance exerted by soil to rotary blade, friction and corresponding torque are the major reasons for causing brittle fracture and stress fatigue fracture [14]. As the two subsystems of rotary cultivator for gearbox and rotary blade, the gearbox transmits the revolving speed into and drives cutter shaft and rotary blade to rotate. To reach the effect of even clods breaking up, it often requires the rotary blade working in high speed. But too high revolving speed fastens the wear of rotary blade. The gearbox of subsystem accelerates the revolving speed (useful function), strengthens the wear of rotary blade of subsystem (harmful function), which is a pair of technical contradiction. This technical contradiction by using general engineering parameters is described as: contradiction between speed (revolving speed) and reliability (rotary blade); contradiction between (revolving speed) and material wear (rotary blade). By checking technical contradiction matrix table and extracting corresponding technical contraction matrix table, it is shown as Table II.

| Improving Parameter | Worsening Parameter |
|---------------------|---------------------|
| 27. Reliability      | 23. Material loss    |
| 11. Pre-compensation | 10. Pre-operation    |
| 35. Performance transformation | 13. Reversal |
| 27. Substitution method | 28. System substitution |
| 28. System replacement | 38. Stepwise oxidation |

Tab. 2 Technical Contraction Matrix Table

Every invention principle in the table can all become the invention principles for solving contradictions. The pre-compensation method is selected in this research as the invention principle of the new technical scheme, and other principles will not be described further. The pre-compensation is to take prepared measures in advance to compensate the relatively low reliability of materials [15]. When rotary cultivator is working, it can pre-destroy the stability and continuity of soil, thus reducing the force exerted by soil to rotary blade.

So, through the application of pre-compensation method, a soil breaking mechanism is added to rotary cultivator. The technical scheme of the new rotary cultivator is shown in Fig. 4, where the soil breaking mechanism can move up and down while the rotary cultivator is running. It can destroy the soil in advance for the first time before the rotary blade breaks the soil, reducing the stability and continuity of the soil that is to be broken, thus reducing the force exerted by the soil when the rotary blade destroys the soil for the second time, reducing the rotary blade wear and protecting the cutter shaft. Comparing the technical scheme of the new rotary cultivator to the current patent technology, there have no repetitive infringements, so the patent application is conducted to this current design scheme. The patent numbers are CN208370416U and CN108401594A, reaching the innovative design objectives.
Fig. 4 Design Scheme of Rotary Cultivator.

1 Shield plate; 2 Soil breaking mechanism; 3 Bevel gear; 4 Rotary blade; 5 Baffle; 6. Incoming rod; 7 Gearbox; 8 Machinery casing

5. Conclusions
The innovative design of service product of technology-effect matrix is applied in this paper. A technical weakness is counter inferred to the design objective, and the final innovative design scheme of rotary cultivator is obtained with TRIZ tool.

- Replace the design objective of seeking with investigating user’s demands in the initial stage of design in the past with technology-effect matrix. Starting from patent perspective, the technology-effect reached by the existed patents and the problems solved are analyzed. While meeting user’s demands, it dramatically reduces the working time in pre-phase and improves the accuracy rate.

- The design objectives are counter inferred by technical weaknesses. The product innovative design is conducted with that as the objective, which compensates the shortcomings in product evolution process, avoids technology repetition and improves the success rate of product innovation.

- The TRIZ tool is applied to answer the design questions, effectively guiding design thinking and speeding up the development cycle of products.

- With the diversification of patent analysis development, more and more tools can visualize the complicated patent data, whereas patent analysis will also provide important data reference for product evolution and innovative design.

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