Identification of Technology Opportunity Based on a Three-Dimensional Technology Effect Model

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Abstract. Intellectual properties are important resources for enterprises to improve competitiveness of their products in the market. Technology effect matrix is a patent map to effectively display the technical information of patents, which provides an effective tool for enterprises to analyze and identify technology opportunities to plan their patent strategy and direction of development. However, the existing matrix analysis method has problems of the information coupling, lack of innovation inspiration for designers, and lack of micro chromatography analysis. This paper combines the technology effect matrix and identification of technology readiness level to build a three-dimensional technology effect model for a comprehensive analysis of patent information. It helps enterprises to effectively formulate scientific technology research and development strategies. Through a cross technology domain patent search, designers can be inspired to develop innovative design with high novelty. The proposed method is applied in the improvement of a powder drying device to demonstrate the effectiveness of the method.

Keywords: Patent map, Technology effect model, Technology opportunity identification, Information visualization, Patent analysis.
DOI: https://doi.org/10.14733/cadaps.2021.97-116

1 INTRODUCTION

With the rapid development of science and technology, intellectual properties have become a key to compete in the market for enterprises. In order to improve the core competitiveness, enterprises are paying more attention to the creation and application of intellectual properties [4]. Patent contains rich information of technology, economy and law with high intelligent values.

According to a survey of the world intellectual property organization, 90% - 95% of inventions can be found in patent documents, 80% of them are not recorded in other documents. Reasonable use of patent information can shorten 60% of research and development (R&D) time and save

40% of R&D funds [13]. Therefore, the rational use of patents is an effective way to obtain the latest technical information and competitive intelligence with the important commercial value.

The number of patent applications in China continues to grow rapidly. The number of patent applications for invention exceeded 1.5 million in 2018, and by the first half of 2019, the number of patent applications for invention had reached nearly 1 million [14]. At the same time, the problem of "large but not strong, many but not excellent" of Chinese patents is increasingly prominent. Therefore, it is urgent to improve the technical quality of patents and cultivate high-quality patents [9]. It is a key issue for how to quickly and accurately collect the required information from many patents, mine patent data and transform it into effective competitive intelligence. It is also essential to make patent knowledge better used by engineering designers.

Information visualization is one of the commonly used methods of data mining. By using functions of the computer graphics to draw a patent map, we can effectively extract the information hidden behind the patent data and improve our understanding and cognition of abstract and complex data [16]. A patent map has the characteristics of intuitionistic and vivid, concise and clear, easy to understand and convenient for data comparison. Drawing a high-quality patent map plays an important role in the effective extraction of patent information.

Technology effect matrix is a kind of the patent map as a common tool for patent qualitative analysis. Where the effect reflects functions that patent includes, and the technology shows the technical scheme used to realize corresponding functions. The technology effect matrix reveals the relationship of the technology and effects [8]. In the matrix, the patent analysis usually uses the number of patents as the display object. The patent information can be analyzed through the mapping relationship of the technology and effects. Results can be clearly displayed to users in a form of charts. It greatly facilitates the search process of useful patent technical data for technology research and development hotspots to make breakthrough. It can also avoid technology minefields to find potential research and development directions.

However, the development level of the technology is not considered when the existing methods identify the technology opportunity through the technology effect matrix. Any technology developed from scratch and then applied needs to go through the process of development and maturity. Generally speaking, the technology development process follows the rule of gradual maturity, and the technology readiness level can measure the stage of technology in the development process [1]. In the process of technology opportunity identification, we should consider the technical blank area and technology readiness level at the same time, then determine the direction of technology research and development, and put forward reasonable suggestions for the strategic development of enterprises.

2 RELATED RESEARCH

There are different methods proposed to build a technology effect matrix and enhance the visualization effect of patent information. Kim [10] suggested specific steps to build the technology effect matrix including the selection of technical keywords of the field theme, building the technical categories and effect categories, and manually reading the patent text to classify all patents into corresponding positions of effect categories. In order to display the patent information more comprehensively, Tseng [18] used text mining to analyze the patent map. This method can mine the potential technical and effect words in the patent text to fully display the patent information and efficiently construct the technology effect matrix.

The patent text can be processed in advance to improve efficiency of building the technology effect matrix. For example, Liu [12] constructed a technology effect matrix based on the classification method. The US patent was used as the classification basis of technical fields, and category of the effect column was determined by manual reading in the patent clustering analysis. Cheng [3] analyzed the patent data of the US Patent and Trademark Office using International Patent Classification and the United States Patent Classification as technical and effect words to construct the technology effect matrix. This method simplified requirements of domain experts in the patent documents classification. Wang [20] defined the classification of technology and effect in advance, the patent text was classified and matched according to key words of patent. The technology effect matrix was established automatically using Patent-TEM software.

The technology effect matrix was also used for technology prediction and analysis. For example, Dong [6] combined a clustering method with the technology effect matrix for technology prediction, and predicted potential technologies according to the technological evolution trend. Zhang [22] introduced a time dimension into analysis of the technology effect matrix, and combined the technology roadmap with the time dimension to show the dynamic change of R&D in the field of technology.

The semantic analysis of patent texts was introduced recently to efficiently and automatically construct a technology effect matrix. For example, Duan [5] proposed a construction process of the patent technology effect map based on a Subject-Action-Object (SAO) structure from the definition and characteristics of SAO. The co-occurrence relationship was used based on the SAO structure to construct the technology effect matrix of patent texts. This method was helpful to find the technical blank area quickly and accurately. Zhang [23] used SAO structure to describe the relationship between entities and concepts for a technology effect knowledge map and the automatic construction of the technology effect matrix based on the knowledge map. It can receive reduced human participation, and improve the speed, interactivity and flexibility of constructing the technology effect matrix.

The existing research on the technology effect matrix mainly involves the effective extraction of technical words and effect words for the rapid and automatic construction of the technology effect matrix. The matrix is then used in the technical layout for the technical blank area and the maximization of enterprises interests. However, there are very few studies on whether the selected technology conforms to the law of technological evolution, or even whether it is the superposition of eliminated technologies when selecting the technical blank area for the opportunity identification. Therefore, in this paper, identification of the technology readiness level is added in the process of building the technology effect matrix, which makes the scientific selection of technology opportunities. Altshuler uses S-curve to describe four stages of the technology readiness level, including introduction, growth, maturity and decline [7]. He developed TRIZ tools to analyze position of the current technology system in S-curve to identify the technology readiness level. After entering the 21st century, methods of identifying the technology readiness level have been further developed, including the patent index method, relative growth rate method, technology life cycle diagram method, and TCT calculation method [2][11][21]. Each of these methods has its own advantages and disadvantages. Considering the characteristics of patents and the difficulty of statistics of patent indicators, this paper uses a technology life cycle diagram to identify the technology readiness level.

In this paper, we combine the technology effect matrix and technology readiness level to propose a three-dimensional technology effect model (3D TEM) construction method to improve the existing methods. The existing methods can only initially identify the technical blank area from a macro perspective, lack of micro level analysis of the technology effect matrix. They are not be able to show the specific patents involved in the technical blank area. In addition, technical words have strong domain characteristics, and the selected technical words are only applicable to specific technologies but not universal, which limits the scope of application of the technology effect matrix. This paper improves these key problems and shows the effectiveness of our method in a case study.

3 PROPOSED METHOD

A three-dimensional technology effect model (3D TEM) construction method is proposed as shown in Figure 1. Details are discussed as follows.

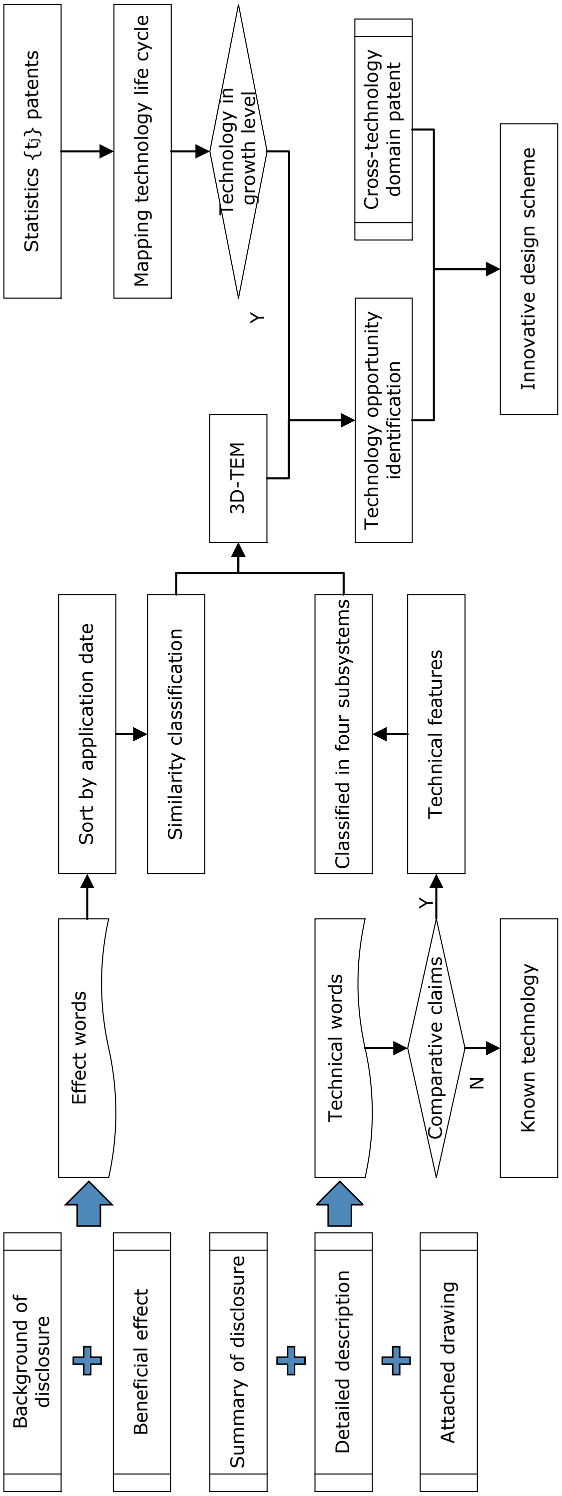

Figure 1: Process of 3D TEM.

3.1 Three-dimensional Technology Effect Model

The traditional technology effect matrix takes technical words and effect words as the coordinate axis, and the size of bubbles at the intersection represents the number of patents. A two-dimensional (2D) technology effect matrix is shown in Figure 2. In the matrix, two large adjacent bubbles at the intersection overlap each other, and the overlapping area produces information coupling, which causes some information loss. In order to reveal the potential information of overlapping positions, technology, effect and patent number are proposed to be three independent coordinates to draw a 3D TEM. The number of patents is drawn in the form of a scatter map to better display the overlapping position information, and these scatter plots are fitted into smooth surfaces. Such a processing method plays an important role in better mining patent knowledge.

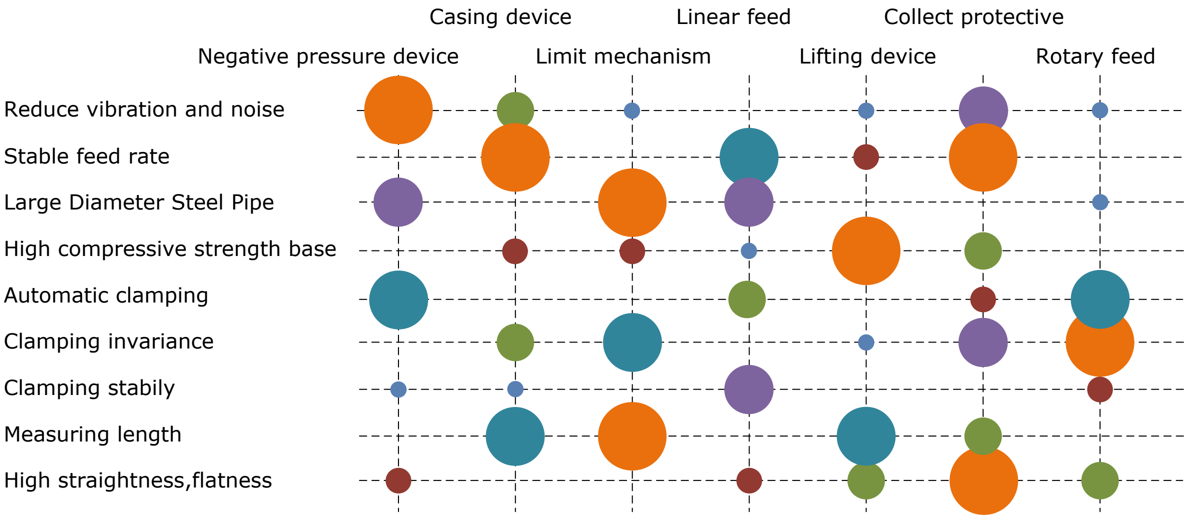

Figure 2: 2D technology effect matrix in cutting machine field.

Coordinate nodes on the effect axis are effect words. Effect words describe functions realized by patents to represent customer requirements. When an existing product in the market cannot meet customer requirements, new products with new functions will be created. In order to protect the core technology of the new products, enterprises can apply for the patent protection. However, according to the intellectual property law, patents can only protect the innovative structure of products, not functions realized by the product. As a result, many competitive enterprises design different innovative structures to achieve the same or similar product functions to meet customer requirements. Therefore, it is very important to select effect words accurately. The accurate description of product functions is the premise of selecting effect words. The patent text is the main basis of extracting the effect words.

In the modeling process shown in Figure 3, relevant patents in the target field are retrieved and sorted according to the application date. Each patent is numbered to build a patent space $A=\{a_i\}(i=1,2,3…m)$. Patent a_i is looked at one by one to sum up its functions. Effect words e_k are extracted from "Background of disclosure" and "Beneficial effect" parts. Effect words e_k are sorted according to date of patent applications. On the basis of the earliest effect words, the effect words with the similar expression are merged. The effect words space $E=\{e_k\}(k=1,2,3…n)$ can finally be constructed.

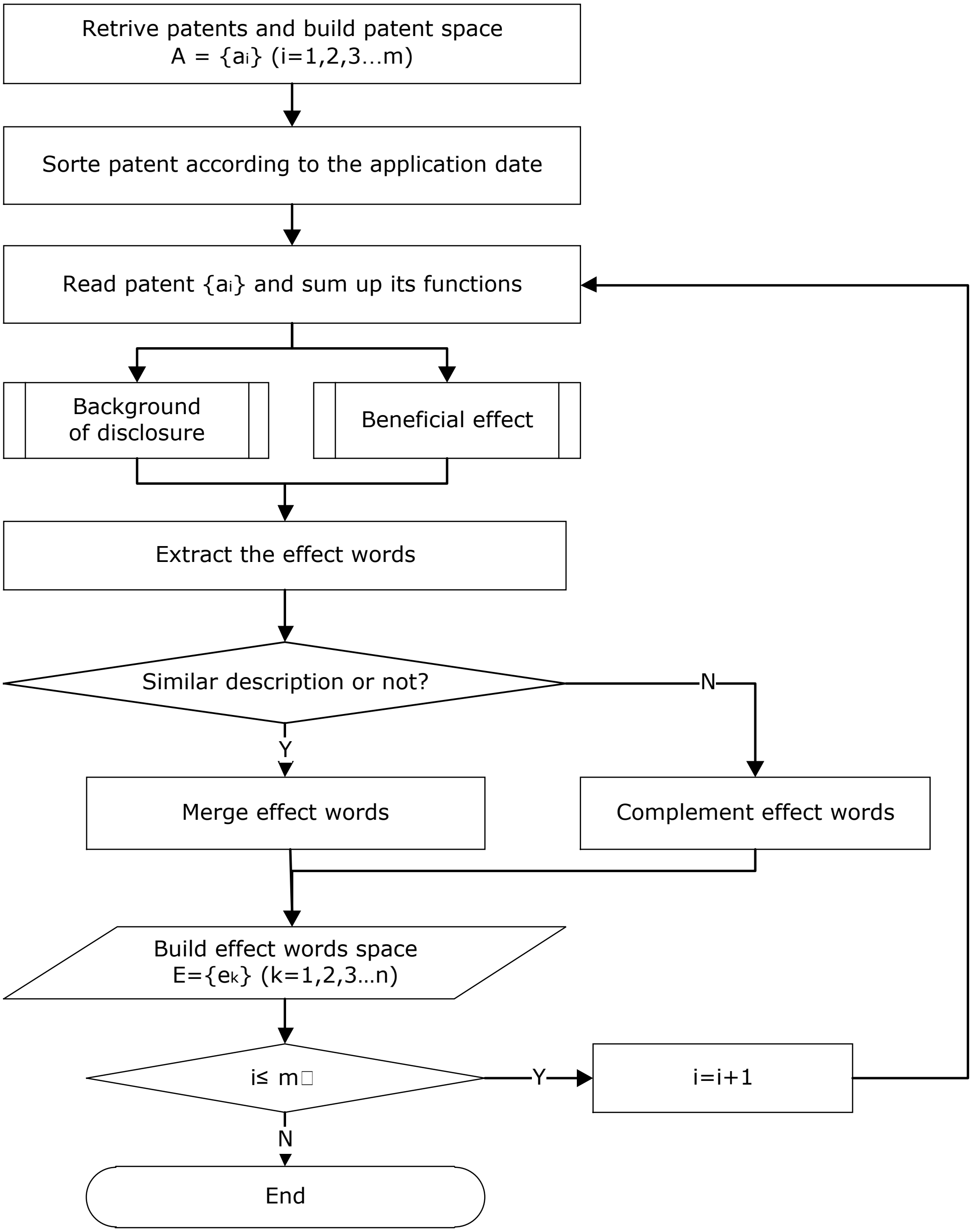

Figure 3: Modeling process of constructing effect words.

Coordinate nodes on the technical axis are technical words. Technical words describe the mechanical structure of patent functions. Due to differences of patent writing methods by different inventors, a same mechanical structure may be expressed in different ways. Even the same mechanical structure can also evolve into different component forms, however they all have the same essential characteristics. Therefore, these technical words with the same characteristics can be merged. The existing merging rules mostly depend on designers' experience. There is not a unified guidance method to follow, which limits applications of the technology effect matrix. Therefore, it is necessary to develop a general method for merging technical words.

Generally, a complete electromechanical product or technical system can be composed of four subsystems: energy system, transmission system, execution system and control system [15], as shown in Figure 4. They are connected to form a complex system with input, output and multiple feedback. Substance, information and energy are input from the external environment to the technical system. The energy system transforms the energy into the special form needed by the technical system. The transmission system transfers the energy from the energy system to the execution system through the mechanical structure. Execution system processes the operation object, complete predetermined functions of the technical system, and outputs new type substance, energy and information. The control system controls and adjusts parameters and behaviors of these subsystems in time according to changes of external environments, so as to coordinate interactions among these subsystems. Because the patent design scheme meets the integrity of the technical system, these four subsystems can be used as technical words.

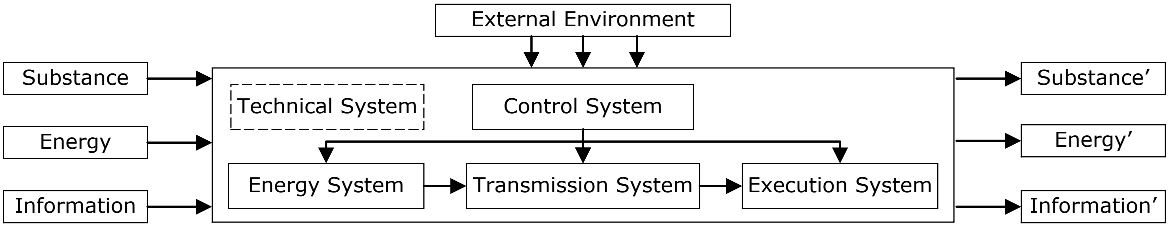

Figure 4: Composition of a electromechanical technical system.

Technical features of the patent can be extracted from "Summary of the disclosure", "Detailed descriptions" and "Attached drawings". These summary of the disclosures describe the main technical features of the patent and the innovative structural design scheme. The working process of the design can also be found to understand the patent. Connection of mechanical components can be found from the drawings to know the position relationship and shape of each component to know innovation of the mechanical structure.

Based on the above analysis, patent technical features can be extracted. In order to identify novelty of the technical features, collected information can be screened according to the protection scope of patent claims. Selected technical features are then classified according to matching relations of technical features and four technical subsystems. A construction process of technical words is shown in Figure 5.

Both numbers of patents and eligible patents are recorded at the intersection of Table 1 to include more patent information in the model. Patents are marked with multiple innovative technical solutions to achieve multiple functions with underline. These patents are of great help for designers to produce innovative design schemes. The patent technology effect matching matrix is shown in Table 1, where t_1 represents energy, t_2 is transmission, t_3 is control, and t_4 is execution.

The number of patents at each intersection of the matrix is represented by h_{kj}. In order to solve the problem of information overlapping in the 2D technology effect matrix, A 3D TEM is proposed using the number of patents as the vertical axis. In order to unify dimensions of the three coordinate axes, Formula (1) is used to remove dimensions of the patent number coordinate axis.

$$h'_{kj} = \frac{h_{kj}}{\max(h_{kj})} \quad (j=1, 2, 3, 4; k=1, 2,3,\ldots n) \tag{1}$$

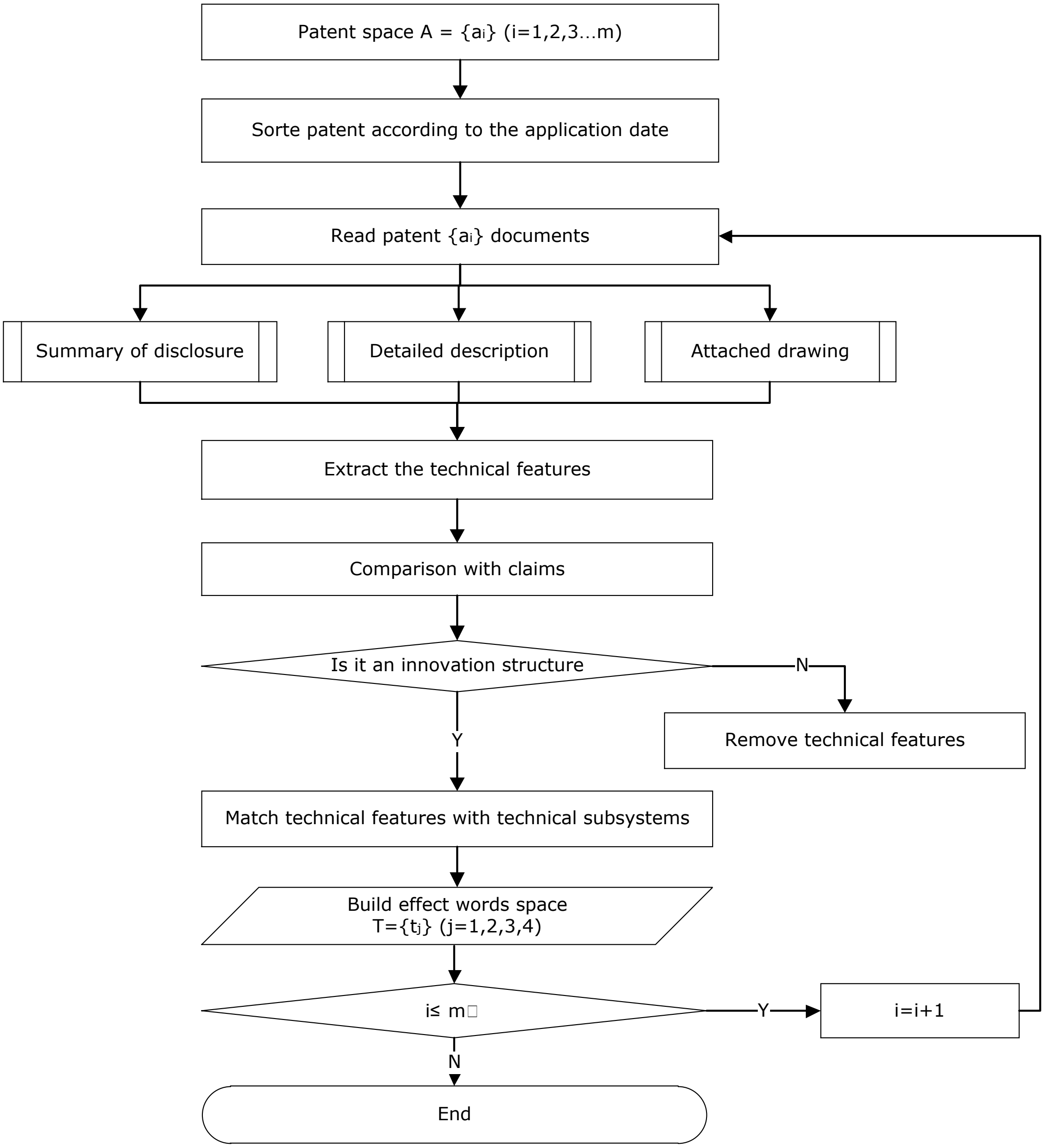

Figure 5: Construction process of technical words.

	t_1	t_2	t_3	t_4
e_1	$\underline{a_1}$, a_2, $\underline{a_6}$ (3)	$\underline{a_4}$, a_7 (2)	$\underline{a_1}$ (1)	a_5, $\underline{a_9}$ (2)
e_2	a_8, $\underline{a_{10}}$ (2)	a_3 (1)	$\underline{a_6}$, $\underline{a_{12}}$ (2)	$\underline{a_{13}}$ (1)
⋮	⋮	⋮	⋮	⋮
e_k	$\underline{a_{12}}$ (1)	$\underline{a_{10}}$ (1)	$\underline{a_4}$ (1)	a_{14},$\underline{a_9}$, $\underline{a_{13}}$ (3)

Table 1: Patent technology effect matching matrix.

The number of patents is used after dimension removal as the vertical axis to draw a scatter plots diagram, as shown in Figure 6. The scatter plots are then connected to draw a 3D TEM of polylines, as shown in Figure 7.

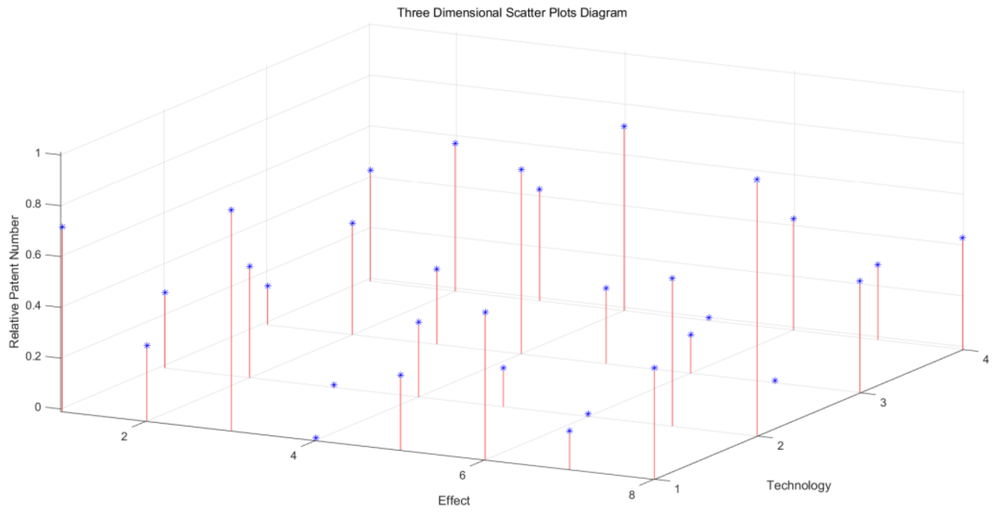

Figure 6: 3D scatter plots.

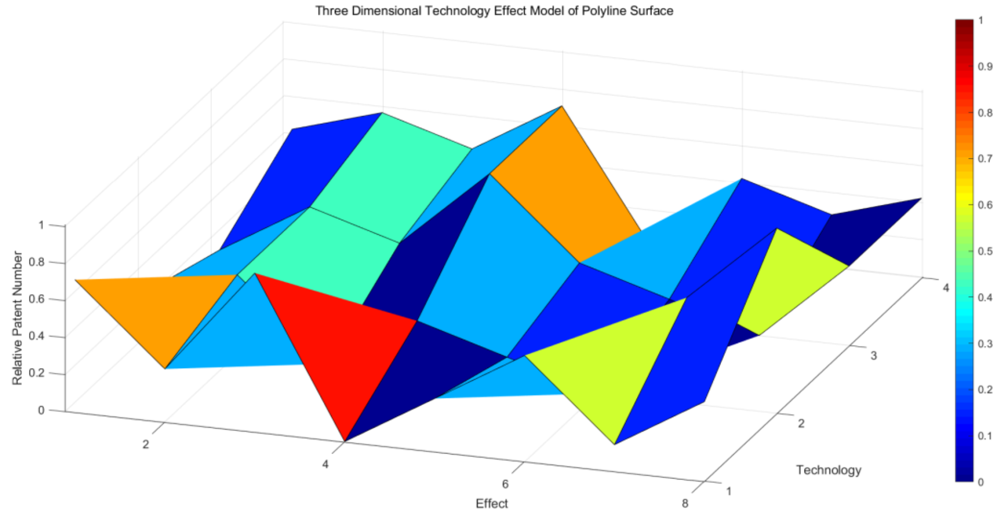

Figure 7: 3D TEM of polylines.

Using the cubic spline interpolation, the 3D TEM of polyline surfaces is smoothed with more patent information displayed at the surface position connected by scatter plots as shown in Figure 8. The interpolation method adopts a piecewise cubic Hermite interpolation method using Formula (2).

$$S(x)=\sum_{j=0}^{n}[y_j a_j(x)+m_j\beta_j(x)] \tag{2}$$

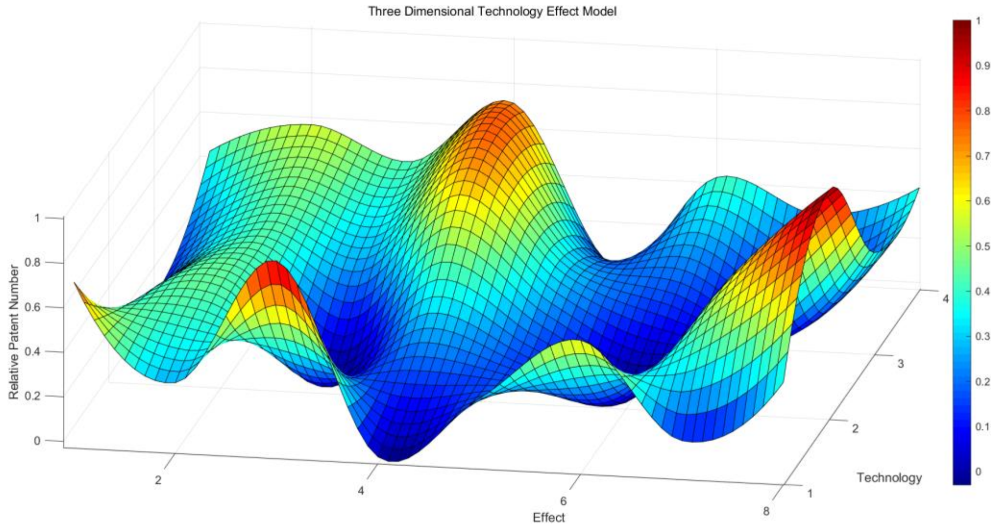

Figure 8: 3D technology effect model.

3.2 Identification of Technology Readiness Level

The 3D technology effect model can judge the patent layout easily. The purpose of identification of technology readiness level is to screen out more development potential technologies. The combination of the two methods can identify technology opportunities more scientifically. After forming 3D TEM, the technology readiness level is identified in four types of technologies mentioned in Figure 4. There are many methods to study the technology readiness level, such as patent index method, relative growth rate method, TRIZ tools, and TCT calculation method [2][11][17][21]. By analyzing the above research results, I summarized the characteristics of each stage of the technology readiness level as shown in Table 2.

Level	Feature	Strategy
Introduction	There are few patent applications, technology R&D activities have just started.	Make full use of resources in the system.
Growth	The product market expanding constantly with the development of technology. The number of enterprises involved has also increased, and the number of patent applications has expanded.	Promote the product performance to the best and seize the market opportunity.
Maturity	The amount of participating enterprises decreases. The growth rate of patent applications declines.	Simplify product systems and improve appearance.
Decline	Enterprises withdraw from the market as the profits shrink. The growth rate is negative.	Looking for alternative technologies for new areas.

Table 2: Four stages of the technology readiness level.

Distinguishing the development level of a technology is essential for enterprises to make correct decisions for R&D directions, be competitive in the market and obtain high profits of the technology located in a growth level. This paper chooses the technology life cycle diagram method to identify the technology readiness level. The development level of four types of technology is analyzed in order to select the technology located in the growth stage for development.

Generally, the number of patent applications can reflect the degree of technological development activities, and the number of applicants can reflect enterprises or individuals involved in technological competition. Using data of patent applications and applicants varying in time, relationships of data can be drawn in a technology life cycle diagram as shown in Figure 9.

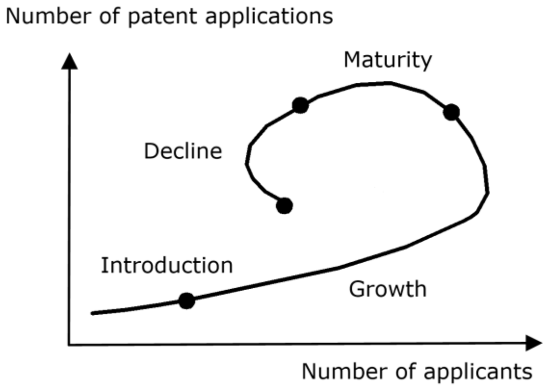

Figure 9: Technology life cycle standard diagram.

4 CASE STUDY

With the rapid increased energy consumption, it has become an important issue to improve the energy utilization of mechanical equipment. The energy used in drying equipment accounts for about 12% of the total energy consumption in the China national economy with an annual growth rate of 5% [19]. Lithium manganate, a powder material of lithium batteries, needs to be dried before the application. The humidity of its powder before drying is about 0.5%. The requirement of humidity after drying is less than 0.01%. It is an urgent task to develop a sustainable drying equipment for the energy-saving.

4.1 Construction of 3D TEM

We use the lithium cobaltate powder drying technology as an example to illustrate the use of 3D TEM. 2982 invention patents are obtained by searching patents with the keyword of "powder drying". Considering the timeliness of patents, the application duration is limited from January 1, 2017 to December 31, 2019. Research fields are limited to industry, transportation, metallurgy, electricity and mechanical engineering. A total of 214 patents are obtained after screening.

All patents are read one by one to extract their effect words from the background of disclosure and beneficial effects. The effect words are then merged with similar expressions, and sorted according to the patent application date. 22 effect words are finally extracted as shown in Table 3.

No.	e_1	e_2	e_3	e_4	e_5
Content	Efficient	High dry quality	Feeding accuracy	Comminuted powder	Low loss
No.	e_6	e_7	e_8	e_9	e_{10}
Content	Thorough drying	Harmless powder	Chemically stable powder	Low pollution	Raw materials mixed evenly

No.	e_{11}	e_{12}	e_{13}	e_{14}	e_{15}
Content	Safer operation	Save raw materials	Non-caking powder	Energy conservation	Uniform drying
No.	e_{16}	e_{17}	e_{18}	e_{19}	e_{20}
Content	Simple structure	Easy to clean	Explosion proof, No static	Convenient operation	Cost reduction
No.	e_{21}	e_{22}			
Content	Cooling rapidly	High reliability			

Table 3: Effect words of powder drying technology.

Technical features are extracted from patent documents according to the protection scope of claims. The well-known technology and technical features protected by patents are distinguished. Based on four kinds of technical words, technical features are classified. A technology effect matching matrix is finally constructed according to technical words and effect words as shown in Table 4. The matrix intersection parts are the number of co-occurrence patents.

After the data in Table 4 is normalized by Formula (1), a 3D scatter plots diagram is formed as shown in Figure 10. Vertexes are connected in the diagram to form a 3D technology effect model of the polyline surface. The curved 3D surface is smoothed using the cubic spline interpolation as shown in Figure 11.

	t_1	t_2	t_3	t_4
e_1	24	27	30	33
e_2	10	14	8	9
e_3	4	11	9	10
e_4	5	28	15	21
e_5	2	9	6	5
e_6	8	6	8	5
e_7	4	5	7	8
e_8	15	17	13	7
e_9	7	17	10	12
e_{10}	9	22	13	10
e_{11}	7	7	10	5
e_{12}	7	13	11	9
e_{13}	9	16	13	15
e_{14}	13	17	12	6
e_{15}	3	10	9	10
e_{16}	6	13	14	9
e_{17}	5	14	11	10
e_{18}	3	3	3	3
e_{19}	5	18	12	14
e_{20}	10	14	11	11

e_{21}	4	5	3	5
e_{22}	4	7	12	3

Table 4: Technology effect matching matrix of powder drying technology.

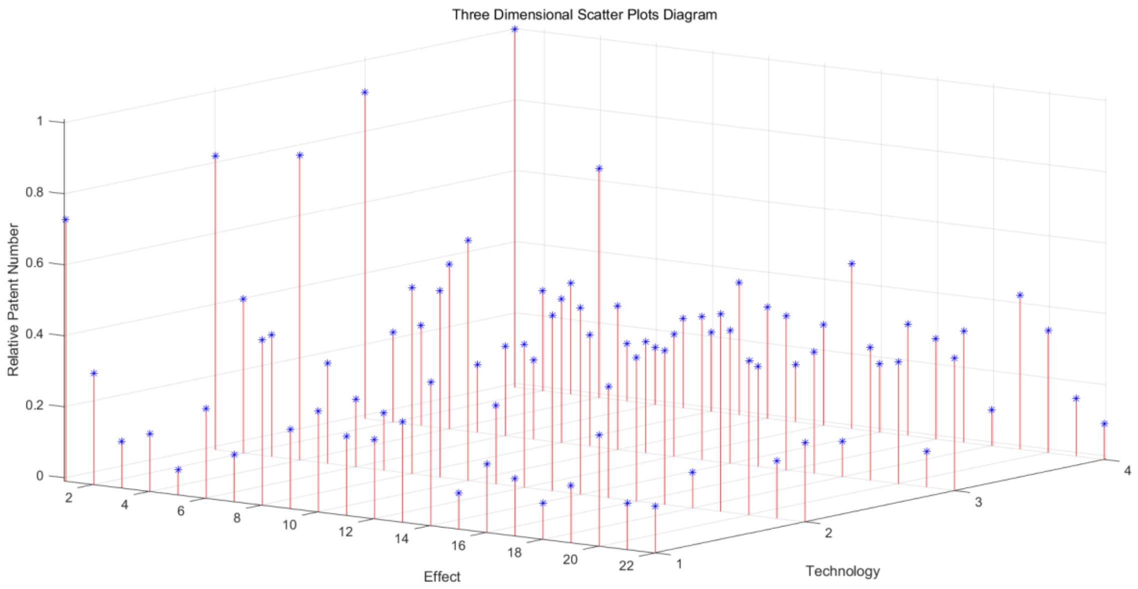

Figure 10: 3D scatter plots diagram of powder drying technology.

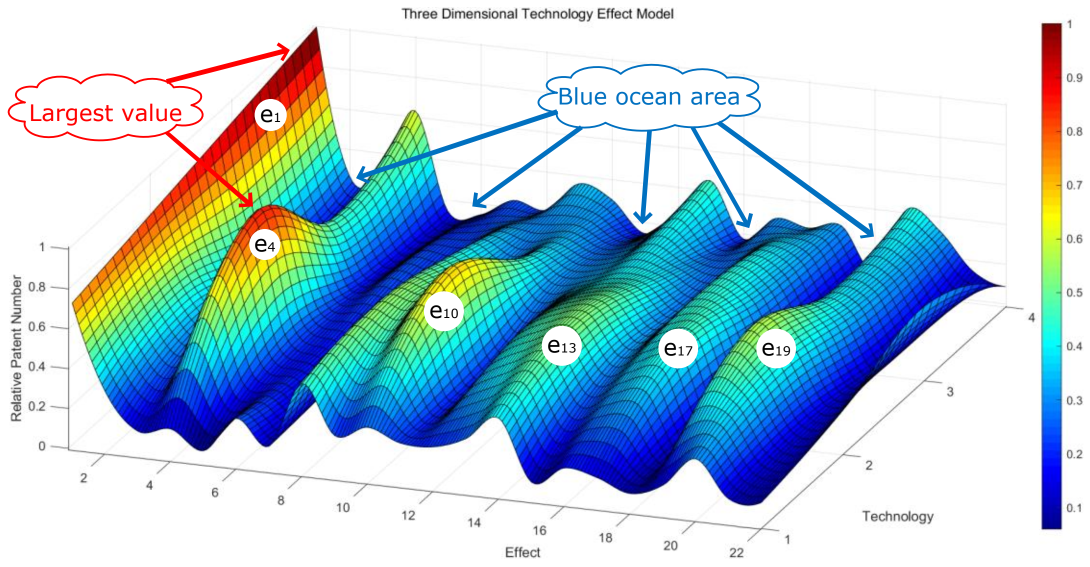

Figure 11: 3D TEM of powder drying technology.

In Figure 11, the overall shape is wavy. The two earliest appearing effect patents of e_1 and e_2 have the largest values as shown in the dark red area, which shows that improving drying efficiency and quality is the enterprises focused area. Functions realized by the patent reflect customer requirements in the market. Since the existing products cannot meet the customer requirements, it will stimulate enterprises to develop new technologies to achieve new functions. Therefore, the effect words in the chronological order perfectly explain the evolution trend of customer requirements.

Two adjacent effect words indicate that they appear next to each other in time. When the market appears new requirements, there will be corresponding functions recorded in patents appeared. In order to share market interests, many enterprises create different mechanical structures to achieve similar functions. As time pass, the technology tends to be saturated. New functions of auxiliary original functions will appear in the market, and the patent technology will be further improved and developed. When original functions of products cannot meet needs of customers, new technologies with new functions are born to enter the next cycle of functions from perfection to replacement. That is reason of the 3D TEM of powder drying technology is wavy on the technical axis as a whole. For example, there are many patents located in e_1, e_4, e_{10}, e_{13}, e_{17}, e_{19} coordinate notes in Figure 11, forming a shape of the mountain peak. A canyon is formed between the two peaks showing blue ocean areas. The number of patents in the blue ocean area is small because many enterprises did not pay enough attention to the corresponding product functions for the corresponding technology scheme. For the technology opportunity identification, these blue ocean areas are preferable directions for the enterprise strategic development. According to the evolution trend of 3D TEM of the powder drying technology, it can be identified that function e_{22} has started to rise. Many enterprises will be committed to improve the reliability of equipment in the near future. Function e_{23} also shows an upward trend. For red ocean areas with a large number of patents, enterprises should carefully consider the strategic layout.

On the technology axis, the number of patents tends to be more in the front and less in the back. This is because the energy consumption of powder drying operations is very high. No matter which function is realized, improving the effective utilization rate of energy and reducing energy consumption are first issues to be considered. With the continuous maturity of mechatronics technology, the development trend of drying equipment will be improvement of the automation degree of equipment from the perspective of control technology to reduce the human participation and improve the drying efficiency. Relevant mechanical structures should be developed.

4.2 Technology Life Cycle Diagram

The technology life cycle diagram shows four kinds of technical words respectively to identify each technology readiness level. Table 5 shows the distribution of patents according to t_1 technical words. The number of patents with multiple functions is only counted once. 164 patents are obtained after deleting duplicate serial numbers. These patents are sorted according to the application date. The technology cycle diagram of t_1 technical words is formed in Figure 12 (a) based on time between the number of patent applications and applicants. Comparing with the standard diagram to decide the readiness level, it can be seen that the energy technology is located in the introduction level. The technology life cycle diagram of the other three types of technical words are also drawn respectively in Figures 12 (b)-(d). It can be identified from the curve shape that the transmission technology is located in the late stage of growth, the control and execution technologies are located in the early stage of growth.

$\{e_k\}$	Patent No.
e_1	a_1, a_{13}, a_{25}, a_{31}, a_{44}, a_{49}, a_{52}, a_{53}, a_{71}, a_{121}, a_{125}, a_{126}, a_{127}, a_{129}, a_{130}, a_{134}, a_{137}, a_{138}, a_{148}, a_{170}, a_{171}, a_{178}, a_{209}, a_{186}(24)
e_2	a_3, a_{23}, a_{41}, a_{45}, a_{50}, a_{60}, a_{118}, a_{114}, a_{122}, a_{133}(10)

e_3	a_{89}, a_{98}, a_{140}, a_{147}(4)
e_4	a_{38}, a_{40}, a_{83}, a_{125}, a_{142}(5)
e_5	a_{123}, a_{145}(2)
e_6	a_5, a_{33}, a_{112}, a_{127}, a_{140}, a_{149}, a_{161}, a_{182}(8)
e_7	a_5, a_{51}, a_{112}, a_{124}(4)
e_8	a_{43}, a_{49}, a_{51}, a_{55}, a_{71}, a_{78}, a_{81}, a_{94}, a_{112}, a_{125}, a_{127}, a_{145}, a_{166}, a_{167}, a_{187}(15)
e_9	a_{51}, a_{68}, a_{74}, a_{111}, a_{132}, a_{140}, a_{155}(7)
e_{10}	a_{13}, a_{25}, a_{33}, a_{87}, a_{94}, a_{120}, a_{129}, a_{133}, a_{143}(9)
e_{11}	a_{49}, a_{73}, a_{100}, a_{110}, a_{115}, a_{116}, a_{121}(7)
e_{12}	a_6, a_{25}, a_{74}, a_{117}, a_{156}, a_{182}, a_{184}(7)
e_{13}	a_{52}, a_{76}, a_{103}, a_{109}, a_{118}, a_{127}, a_{129}, a_{133}, a_{164}(9)
e_{14}	a_{15}, a_{23}, a_{32}, a_{45}, a_{50}, a_{69}, a_{85}, a_{109}, a_{116}, a_{119}, a_{132}, a_{153}, a_{159}(13)
e_{15}	a_{41}, a_{51}, a_{83}(3)
e_{16}	a_{51}, a_{72}, a_{80}, a_{85}, a_{96}, a_{97}(6)
e_{17}	a_{53}, a_{69}, a_{80}, a_{88}, a_{128}(5)
e_{18}	a_{127}, a_{157}, a_{166}(3)
e_{19}	a_{44}, a_{46}, a_{70}, a_{101}, a_{135}(5)
e_{20}	a_{56}, a_{59}, a_{69}, a_{71}, a_{94}, a_{114}, a_{123}, a_{132}, a_{139}, a_{146}(10)
e_{21}	a_{70}, a_{85}, a_{89}, a_{153}(4)
e_{22}	a_{121}, a_{126}, a_{138}, a_{145}(4)

Table 5: Patent number in line with t_1.

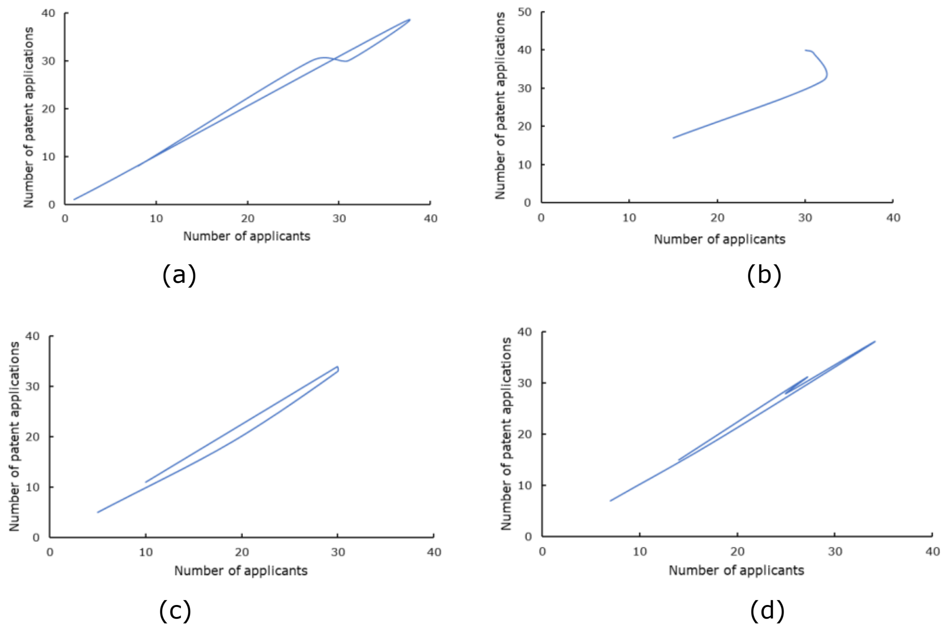

Figure 12: Technology life cycle of four types of technologies. (a) t_1 technology life cycle diagram; (b) t_2 technology life cycle diagram; (c) t_3 technology life cycle diagram; (d) t_4 technology life cycle diagram.

In order to quickly maximize enterprise benefits, the transmission, control and execution should be selected as the main research and development technology. Cross sectional drawings at t_2, t_3, and t_4 coordinate points in the 3D TEM are shown in Figure 13. Blank areas are selected such as e_3, e_7, e_{11}, e_{18}, e_{21} coordinate notes shown in Figure 13. By comparing the blank areas with blue ocean areas discussed in Section 4.1, the technology opportunity of powder drying is finally identified including improving the drying effect of powder, improving the effective utilization of energy, simplifying the operation of drying equipment, improving the safety of equipment operation, drying the powder inside and eliminating static electricity thoroughly.

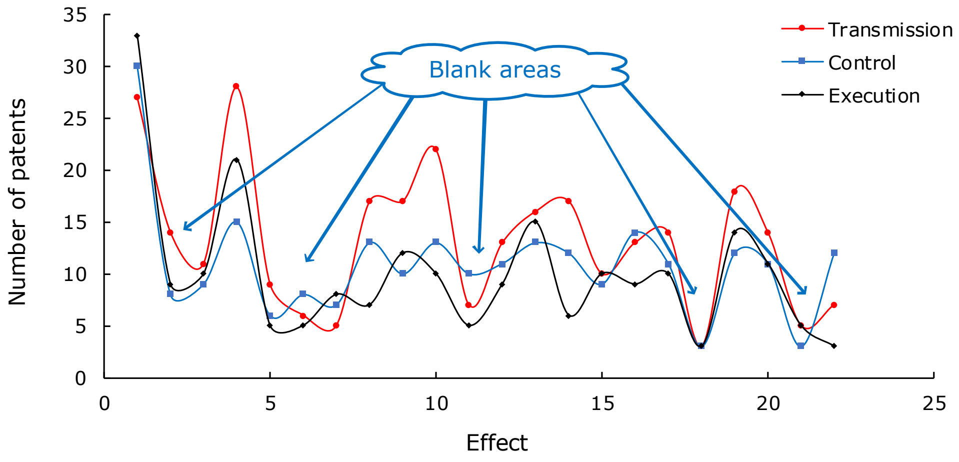

Figure 13: Technical node sectional drawings.

In the design improvement, patents that span three technology categories are mainly used for references, including a_8: CN201710242862.9, a_{52}: CN201711193866.9, a_{100}: CN201810349904.3, and a_{119}: CN201810613408.4. The circulating drying is used to achieve the efficient utilization of energy, automation of the drying equipment is improved to reduce manual operations, and drying path of the drying pipe is increased to improve drying efficiency and quality. A new lithium cobaltate powder drying structure is finally developed. The 2D drawing is shown in Figure 14.

The working process of the short tube air dryer is as follows. The wet lithium manganate powder is added from feeding tube to inner tube, and a weighing device is added at the bottom of the dryer to accurately control the weight of added powder to improve the working efficiency. The whole drying process is divided into four steps: Adding material, vacuum pumping, cyclic drying and collecting powder. When the drying process starts, valves are closed for vacuum treatment to helps separate free water molecules from the powder. Then the dry hot nitrogen is blown from the air-jet tube. The hot nitrogen blows up the powder into the outer tube. Cyclone exhaust tube replaces the cyclone separation structure in the original design for the effective separation of wet gas and dry powder. At the same time, the powder blown out from the exhaust tube has a great tangential speed. The powder hits the inner wall of return flow tank rapidly for crushing effect of powder. The powder falling from the outer tube will enter the inner tube again from small holes under the negative pressure for the second circulation drying. The wet powder and dry nitrogen are fully contacted in the dryer for the heat exchange, the wet water vapor is discharged from the return tube, and the lithium manganate powder with humidity up to standard is left in the dryer. Finally, the dried lithium manganate powder is collected through outlet tube. The work flow is shown in Figure 15, in which the blue arrow represents the powder, the brown arrow represents the extracted air, the red arrow represents the dry hot nitrogen, and the red fork represents the closed valve.

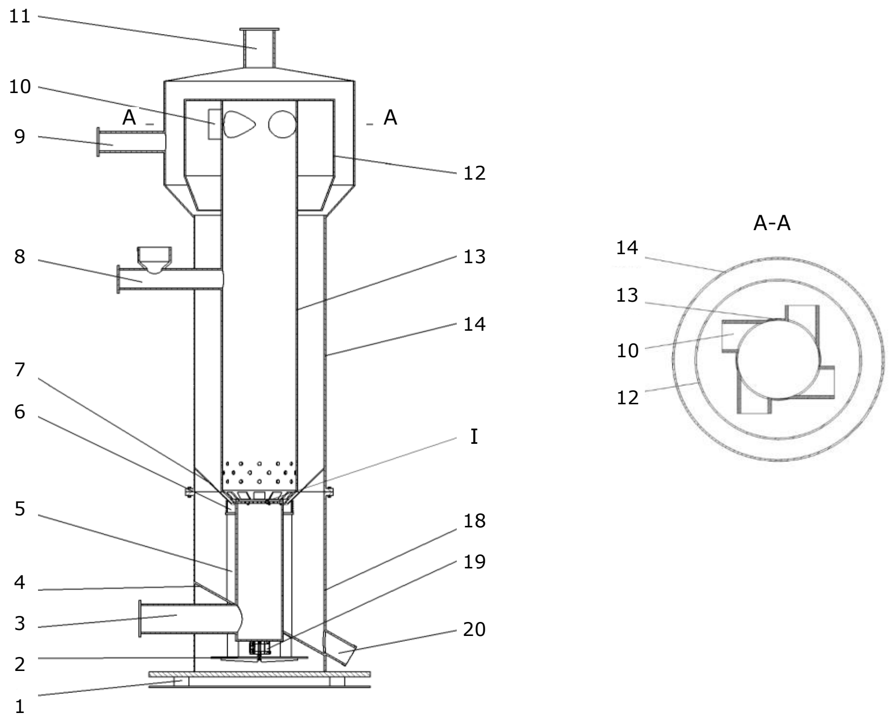

Figure 14: A powder circulating short tube air dryer. 1. Weighing device; 2. Connecting disc; 3.Air-jet tube; 4. Inclined slide plate; 5. Connecting rod guide tube; 6. Connecting rod; 7. Small holes; 8. Feeding tube; 9. Vacuum exhaust tube; 10. Cyclone exhaust tube; 11. Return tube; 12. Return flow tank; 13. Inner tube; 14. Outer tube; 15. Ring pressure net plate; 16. Screen mesh support plate; 17. Screen mesh support plate; 18. Return gas tank lower section; 19. Cylinder; 20. Outlet tube.

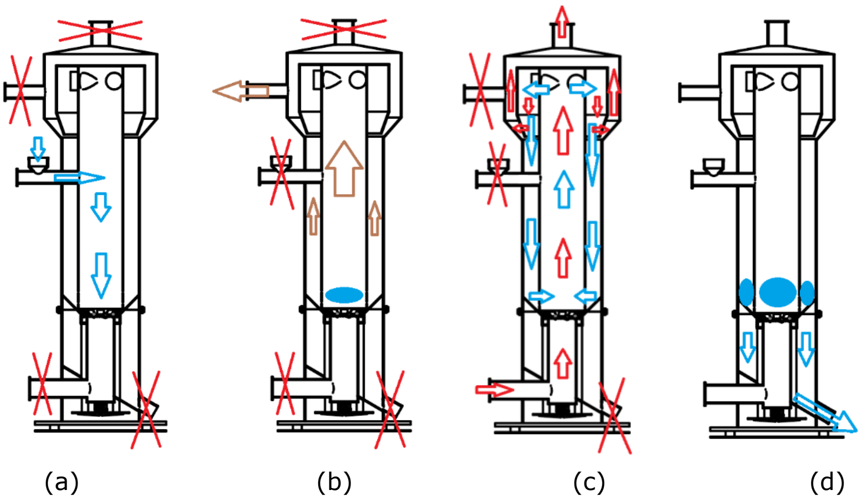

Figure 15: Short tube air dryer workflow. (a) Adding material, (b) Vacuum pumping, (c) Cyclic drying, (d) Collecting powder.

Comparing with the original straight tube air dryer with a height of about 15 meters, the redesigned structure is only about 2 meters high. It is more convenient for making and installing. The powder circulating dryer is designed as a double-layer structure of the outer tube and inner tube, which improves the heat preservation effect and reduces the energy consumption. The tangential structure replaces the original designed cyclone separator, uses the function of pulverizing powder, and simplifies the mechanical structure. The powder is shuttled between the inner tube and outer tube for many times to ensure that the powder with different humidity is evenly stirred, and at the same time for the efficient utilization of energy. Considering that the chemical properties of lithium cobaltite powder and nitrogen are stabled, there is no structure designed for the electrostatic explosion. This innovation structure has applied for patent.

In order to assist designers to establish 3D TEM and technology life cycle diagram, an APP is developed using MATLAB. The APP operation interface is shown in Figure 16.

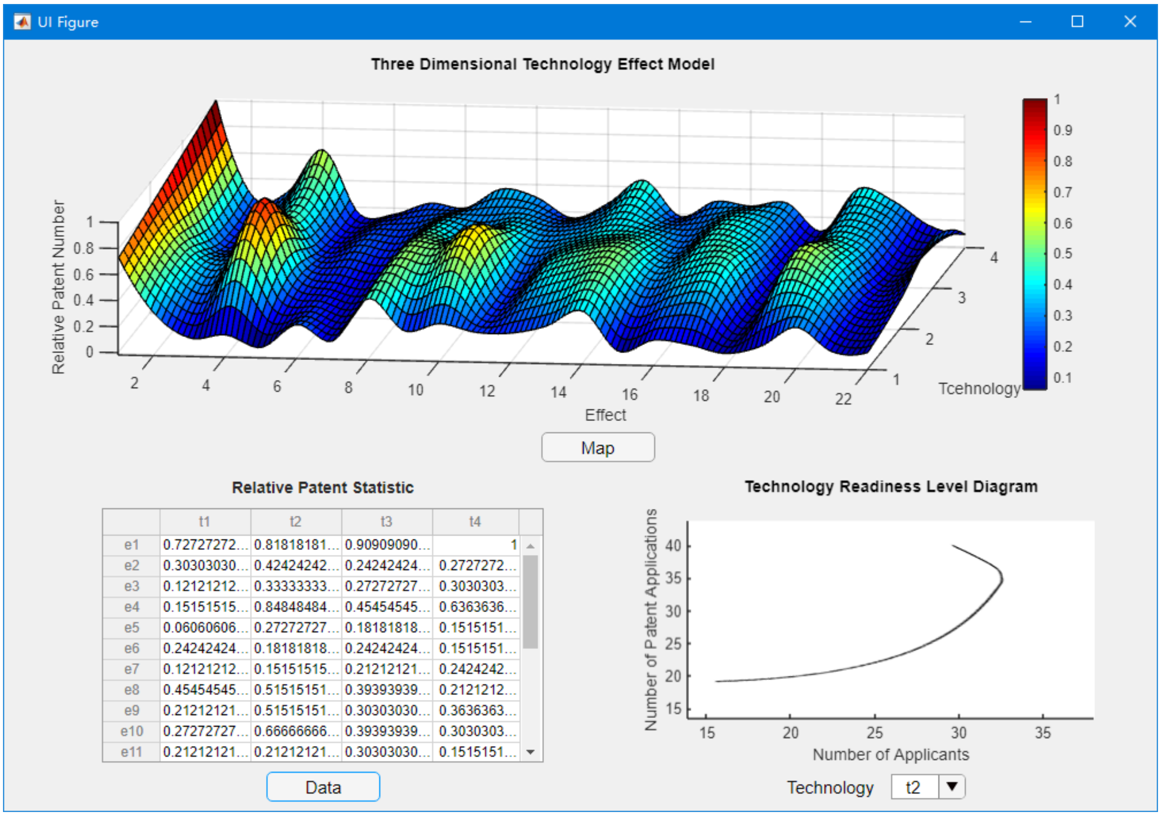

Figure 16: APP operation interface.

5 CONCLUSION

In this paper, two methods of the technology effect matrix and technology readiness level were integrated for building a 3D technology effect model. The model combined technical features, effect features and patent number in order to optimize the analysis result using the technology effect matrix, decouple the 2D coordinate axis data and enrich the analysis content.

The 3D TEM can effectively identify technology opportunities. The model enhances the visualization effect of comprehensive patent information. The patent layout of competitors can be identified accurately. Through analysis of the patent trend, suggestions can be made to the development opportunity and R&D directions. Based on the identified technology readiness level using the technology coordinate points break-out section, the suitable technology can be chosen for R&D to maximize interests of enterprises. In the process of the patent statistics, patents can be recorded in detail for a number of innovative technologies and multiple functions. These patents can better inspire designers to design innovative structures and propose high-quality patents.

Effectiveness of the proposed method was verified in the improvement of a powder drying equipment. Patents were analyzed in the field of powder drying, effect words were sorted in the chronological order to form a 3D TEM that was used to identify the technology opportunity. According to the evolution trend of the number of patents, suggestions were made for the technology layout of enterprises. Combined with identification of the technology readiness level, the key research and development direction of powder drying technology were determined. According to the inspiration of co-occurrence patent, the improved powder dryer structure was designed and applied for patent.

In the process of building 3D TEM, the extraction and selection of patent information were processed manually, which limits the method efficiency. In the future, we will develop the method for efficient patent text mining to speed up the extraction of patent information.

6 ACKNOWLEDGEMENT

This paper was sponsored by the National Natural Science Foundation of China (Grant Nos. 51675159) and the National Special Project for Local Science and Technology Development (Grant Nos. 18241837G).

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REFERENCES

[1] Beims, R. F.; Simonato, C. L.; Wiggers, V. R.: Technology readiness level assessment of pyrolysis of trygliceride biomass to fuels and chemicals. Renewable and Sustainable Energy Reviews, 112, 2019, 521-529. https://doi.org/10.1016/j.rser.2019.06.017

[2] Cao, L.: Research on patent information analysis oriented to patent strategy, Science and Technology Management Research, (3), 2005, 97-100. https://doi.org/10.3969/j.issn.1000-7695.2005.03.032

[3] Cheng, T. Y.; Wang, M. T.: The patent-classification technology/function matrix-A systematic method for design around, Journal of Intellectual Porperty Rights, 18(2), 2013, 158-167. https://pdfs.semanticscholar.org/afe9/65162379910fff9d68b8335dc04bd7315c51.pdf

[4] Cheng, S. Y.; Wang, R.; Yang, X. R.; Zhao, R. L.: Methods of patent around design based on TRIZ, Packaging Engineering, 35(22), 2014, 68-72. http://doi.org/68-72. 10.19554/j.cnki.1001-3563.2014.22.016

[5] Duan, Q. F.; Jiang, B. J.: Building patent technology - effect map based on SAO structure, Journal of Modern Information, 37(06), 2017, 48-54. https://doi.org/10.3969 /j.issn.1008-0821.2017.06.008

[6] Dong, S. J.; Jun, S.; Sang, S. P.: Technology forecasting using matrix map and patent clustering, Industrial Management & Data Systems, 112(5), 2012, 786-807. https://doi.org/10.1108/02635571211232352

[7] Gong, Y. M.; Ding, M. F.: Apply TRIZ to technology forecasting, R&D Management, (10), 2004, 77-81. https://doi.org/10.13581/j.cnki.rdm.2004.05.013

[8] He, Y.; Li, Y.; Meng, L.: A new method of creating patent technology-effect matrix based on semantic role labeling//2015 International Conference on Identification, Information, and Knowledge in the Internet of Things (IIKI). IEEE, 2015, 58-61. https://doi.org/10.1109/IIKI.2015.19
[9] Hirschey, M.; Richardson, V. J.: Are scientific indicators of patent quality useful to investors?, Journal of Empirical Finance, 11(1), 2004, 91-107. https://doi.org/10.1016/j.jempfin.2003.01.001
[10] Kim, S.; Kim, S. Y.; Hong, S. W., Coh, B. Y.: Applying pagerank to Patent, CIT, 20, 2013, 30. https://doi.org/10.13140/2.1.1327.0725
[11] Lou, Y. M.: The study on technological trend based on the patent analysis, Master thesis, Beijing University of Technology, 2011.
[12] Liu, K.; Yen, Y.; Kuo, Y. H.: A quick approach to get a technology-function matrix for an interested technical topic of patents. International Journal of Arts and Commerce, 2(6), 2013, 85-96. https://ijac.org.uk/images/frontImages/gallery/Vol._2_No._6/10.1.pdf
[13] Li, H.; Yuan, J. F.; Tan, R. H.; Peng, Q. J.: Design around bundle patent portfolio based on technological evolution, Chinese Journal of Mechanical Engineering, 32(1), 2019, 86. https://doi.org/10.1186/s10033-019-0400-4
[14] National intellectual property administ, http://www.sipo.gov.cn/tjxx/
[15] Pahl, G.; Beitz, W.: Engineering design-A systematic approach, Springer-Verlag Press, London, 2000.
[16] Suzuki, S. -I.: Introduction to patent map analysis, Japan Patent Office Press, Japan, 2011.
[17] Tan, R. H.: TRIZ and applications: the process and method of technological innovation, Higher Education Press, Beijing, 2010.
[18] Tseng, Y. H.; Lin, C. J.; Lin, Y. I.: Text mining techniques for patent analysis, Information Processing & Management, 43(5), 2007, 1216-1247. https://doi.org/10.1016/j.ipm.2006.11.011
[19] Wang, C.; Tan, H. Q.: The research progresses and prospects of drying technology in China, Journal of Agricultural Mechanization Research, 31(12), 2009, 221-224+227. https://doi.org/10.13427/j.cnki.njyi.2009.12.036
[20] Wang, L.; Zhang, D. R.; Zhang, X. H.; Wu, M.; Yang, X. W.: Realization of technology/effect maps generating based on subject automatic indexing, Data Analysis & Knowledge Discovery, (5), 2013, 80-86. http://ir.las.ac.cn/handle/12502/6254
[21] Zhong, H.; Deng, H.: Patent portfolio analysis based on technology life cycle, Library and Information Service, 56(18), 2012, 87-92. https://doi.org/CNKI:SUN:TSQB.0.2012-18-019
[22] Zhang, H.; Zhang, Y. Q.: The construction of three-dimensional technology-effect analysis model: an empirical study, Information Studies: Theory & Application, 41(05), 2018, 74-78. https://doi.org/10.16353/j.cnki.1000-7490.2018.05.014
[23] Zhang, Z. F.; Zhang, J. S.; Yao, C. Q.: A method of constructing patent technology-effect map automatically based on knowledge map, Information Studies: Theory & Application, 41(03), 2018, 149-155. https://doi.org/10.16353/j.cnki.1000-7490.2018.03.028