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Identification of Product Innovation Path Incorporating the FOS and BERTopic Model from the Perspective of Invalid Patents

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Abstract: Under the premise of resource constraint, it is crucial to identify the product innovation opportunities contained in failed patents through external search in order to compensate for the shortcomings of enterprises' own technology. Due to the cost of patent research and development and the risk of infringement, this paper constructs a product innovation identification path that integrates the FOS and BERTopic model from the perspective of invalid patents. The path consists of three stages, including the identification of the problem to be solved by the product based on functional analysis, the extraction of the subject matter elements based on the core failed patent technology, and the generation and evaluation of innovative solutions based on TRIZ theory and the best- worst method (BWM). Finally, the feasibility of the path constructed in this paper is verified by taking a slurry pump as an example. The application results show that the product innovation identification path constructed in this paper can provide theoretical support for enterprises to carry out technological innovation activities efficiently.

Keywords: invalid patent; TRIZ; BERTopic; best-worst method (BWM); functional-oriented search (FOS); slurry pump

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1. Introduction

In the era of knowledge-based economy, as competition in international trade becomes increasingly acute, technological innovation has turned out to be the way for enterprises to enhance their competitive edge and seize market opportunities [1,2]. In addition, many companies are increasing the speed of technological innovation while placing greater emphasis on the layout and protection of their intellectual property and patents [3].

As a tool to break through patent barriers, save resources and reduce costs, patent design not only enables enterprises to accelerate the pace of technological innovation to catch up, but also helps them to leapfrog to the top of the industry [4]. For this reason, many scholars have conducted a lot of research on patent-avoidance design [5–7]. However, few scholars have considered invalid patents as an important source of product innovation identification for enterprises, and the use of invalid patents has two obvious advantages: firstly, there is no need to pay royalties to the inventor, thus reducing the cost of using the patent; secondly, invalid patents are not protected by law, thus reducing the risk of patent infringement [8].

Invalid patents can be used as a technical reference and learning resource. The documentation of an invalid patent may contain the technical thinking, development history and technical details of the innovator. Other researchers or companies can avoid duplication of effort and mistakes by studying invalid patents to learn about previous technological advances and lessons learned.

Invalid patents can stimulate innovation and further research. When a patent lapses, other researchers or companies can improve and innovate based on that technology, thus advancing and developing the technology.

In a sense, therefore, invalid patents may be an important source of product innovation opportunity identification for companies.

To bridge this gap, we construct a pathway for finding product innovation opportunities from invalid patents. To do so, we firstly identify the problem to be solved by the target product through function analysis, conduct a function-oriented search based on the problems, retrieve cross-domain patents and retain the invalid patents; secondly, screen out the core invalid patents based on the evaluation index system, and extract the technical subject matter elements and conduct technology migration based on the BERTopic model; again, generate product innovation solutions based on the TRIZ tool and complete the evaluation of the innovation solutions based on the BWM method; finally, to verify its usability, the method is applied to slurry pump products. The theoretical contribution of this study is an attempt to examine the technical value and application potential of invalid patents. The practical implication is that it will help companies that lack the resources to develop new technologies to identify new business opportunities from the public technology sector.

The remainder of this paper is organized as follows. First, Section 2 presents the related research. Following this, we explain the research framework and methodology in Section 3. In Section 4, the results of the case study are presented. Finally, Section 5 discusses the contributions and limitations of the proposed methodology.

2. Theoretical Background

2.1. Invalid Patents

Patents can be classified according to their legal status into valid patents and invalid patents, a valid patent refers to a patent that has been granted and is in a valid state and protected by patent law, while a lapsed patent refers to a patent that has lost its patent rights or is no longer protected by patent law for various reasons [9]. The invalidity of a patent does not mean that the technical information contained in the patent is obsolete, and technology that is considered obsolete in one field can open up new opportunities in another [10]. It still has important functions such as value analysis, technology development trajectory and determination of R&D direction, and is of great reference value to enterprises in their innovation decisions [8].

The use of an invalid patent has two significant advantages over a valid patent. Firstly, there is no need to pay royalties to the inventor, thereby reducing the cost of using the patent. Secondly, there is no legal protection, thereby reducing the risk of patent infringement. This allows companies to learn similar technologies from invalid patents in order to speed up the process of technological innovation [11].

Specifically, small and medium-sized enterprises can identify technologies that still have market prospects among invalid patents and make use of them, thus saving R&D costs and time. Large enterprises, on the other hand, can build on this foundation by upgrading and developing more advanced technologies, thereby capturing market share [12].

2.2. FOS & TRIZ Theory

Function Oriented Search (FOS) was proposed by Simon Litvin. It is a key problem-solving tool in the problem-solving module of modern TRIZ theory. It solves problems by translating the problem to be solved into a functional language, building a functionalized model and transferring advanced solutions from other fields to this domain [13].

TRIZ is complementary to FOS as one of the most powerful systems innovation approaches [14]. It includes both analytical tools for identifying creative problems as well as sources of solutions. Since the most significant advantage of TRIZ is the elimination of contradictions, many scholars have combined FOS with TRIZ [15,16].

Similar to TRIZ, FOS consists of four steps: ① identify the concrete problem; ② abstract the concrete problem into a conceptual problem; ③ find a conceptual solution to the conceptual problem; and ④ apply the existing solution to the concrete problem [17]. The general process of functional oriented search is shown in Figure 1.

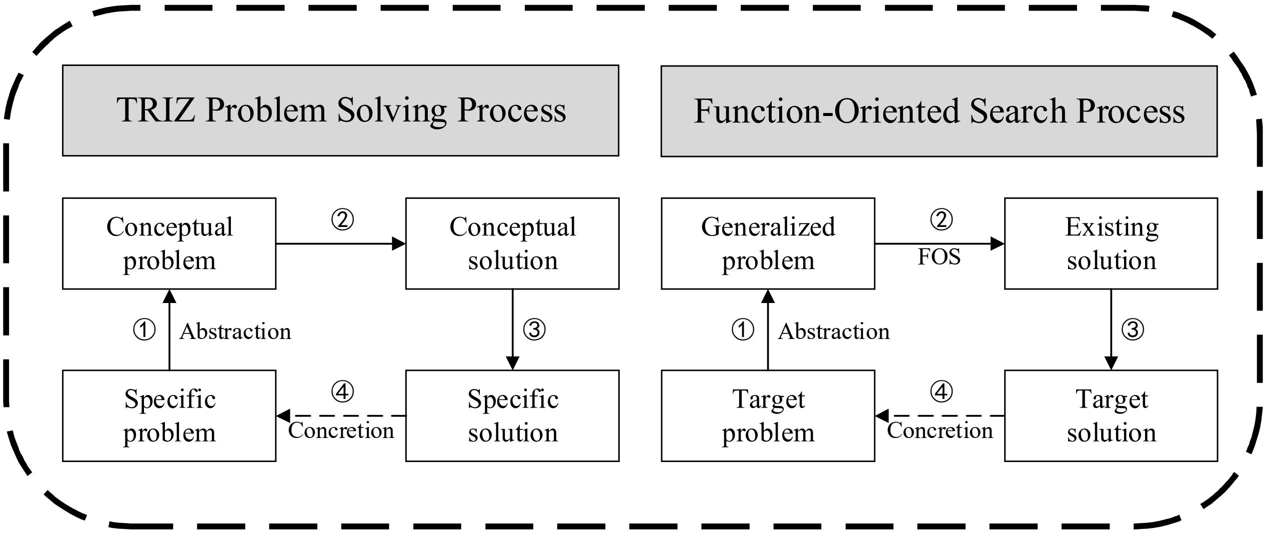

Figure 1. The general process of functional oriented search.

To date, FOS has been widely used in different industries and fields, such as automotive [18], unmanned ships [17] and composite side door impact beams [19], all of which demonstrates its universality. In that sense, this paper proposes to use FOS to conduct a domain-wide search based on the problem to be solved, and in turn to identify more advanced domain solutions.

2.3. BERTopic Model

BERTopic is able to extract technical themes and technological innovation elements from a large volume of patent texts [20]. It consists of three steps: UMAP dimensionality reduction, HDBSCAN clustering, and c-TF-IDF extraction of subject terms. Therefore, it is able to take into account the semantic information of the text more fully than the LDA model [21].

Based on this, scholars have conducted rich research using BERTopic, for example, [22] used tweets from Nigerian bank customers as a dataset and topic modelling. In addition, [23] used clinical records from the Canadian Primary Care Electronic Medical Record for describing and monitoring the primary care system. Ref. [24] applied BERTopic to patents filed with the US Patent and Trademark Office and calculated scores for potential technologies. The above studies demonstrate the universality of BERTopic.

Therefore, in this study, we attempted to apply BERTopic to the core invalid patent dataset for topic extraction.

2.4. The Best-Worst Method

The best-worst method (BWM) proposed by Rezaei is an improved AHP method [25]. Compared with the traditional AHP method, the BWM is easy to handle in terms of achieving consistency and has been widely used in recent years [26].

Ref. [27] introduced a framework for the MCDM process based on the indecisive fuzzy BWM and verified the feasibility and validity of the model. Ref. [28] used the group BWM for rational robot selection and showed that it had better performance with a lower minimum violation rate and smaller total deviation. Ref. [29] used the BWM to illustrate how data can be aggregated and analysed and demonstrated how richer insights can be gained.

Based on this, this paper uses the BWM to evaluate and rank product innovation solutions, providing a reference basis for companies to accurately select product innovation opportunities.

3. Methodology

The proposed method of the product innovation path consists of three steps. The first step involves identifying problems and a functional-oriented search. The second step involves identifying core invalid patents and extracting technical thematic elements. The third step involves innovation solutions' generation and evaluation. The overall research process is shown in Figure 2.

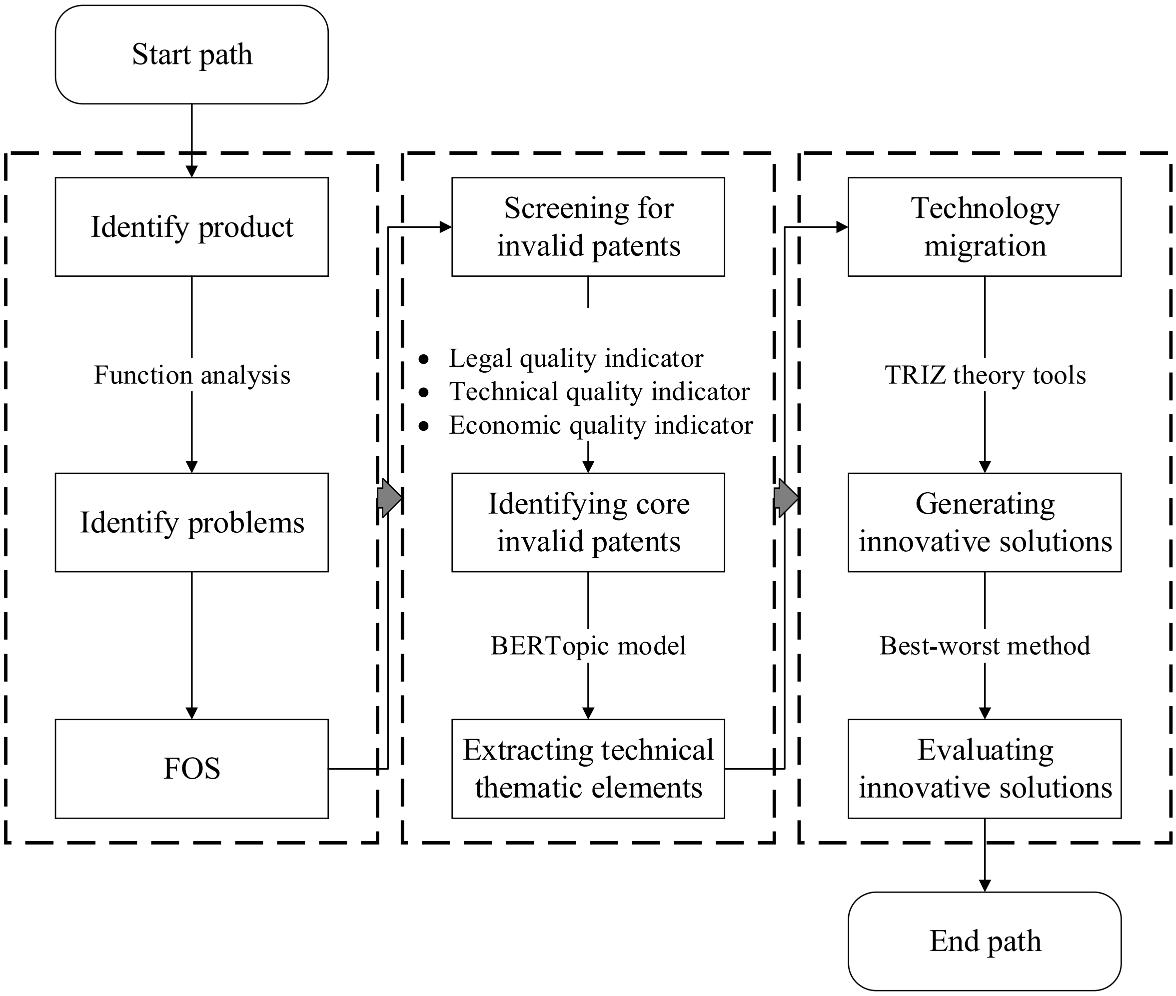

Figure 2. The overall research path.

3.1. Identify Problems and Functional-Oriented Search

As shown in Figure 2, identify problems and functional-oriented search mainly includes the following three steps.

3.1.1. Identify the Target Product

First, the target product needs to be identified. Product development must be fully informed by the resources and user needs of the target product. Mainstream products in the market may be chosen as a benchmark for functional analysis and design evaluation. In the case of slurry pumps, the world-famous slurry pump is the Warman pump, a double-casing solution that was so revolutionary and innovative that it is still used by many pump manufacturers today.

3.1.2. Identify Problems with Function Analysis

From the target product to be solved, its function is analysed and the corresponding search expressions are developed for FOS based on the functional starting point.

3.1.3. Functional-Oriented Search

The description of function is generally divided into three parts: the functional vehicle, the functional object and the verb between them. For example, drilling a hole in a shirt is usually described as drilling a hole in a thin material.

In the development of search expressions, the opinion of domain experts needs to be taken into account. For example, the search expression for drilling a hole in a thin material would be (drilling and material). The accurate description of the function and the scientific formulation of the search expressions are the basis for subsequent domain-wide patent searches. This analysis process is shown in Table 1.

Table 1. The process of obtaining patents in other fields.

Functions	Generalized Functions	Search Expressions	Number of Patents in All Areas
Function 1	Function description 1	Expression 1	Number 1
Function 2	Function description 2	Expression 2	Number 2
...	...	...	...
Function n	Function description n	Expression n	Number n

3.2. Identifying Core Invalid Patents and Extracting Technical Thematic Elements

As shown in Figure 2, identifying core invalid patents and extracting technical thematic elements mainly includes the following three steps.

3.2.1. Screening for Invalid Patents

After collecting patents obtained in other fields, invalid patents need to be screened out according to their legal status, invalid patents that meet the requirements need to be retained. Once these steps have been completed, the data need to be pre-processed to further improve the accuracy and validity of the data analysis. Firstly, duplicate patents and patents that are not highly relevant to the target technology area are filtered out. Secondly, a stop word list is constructed to further filter out punctuation marks, common characters, etc. from the patent text. Finally, a user-defined dictionary is constructed and divided into words to avoid segmentation of specialized words in the target technology area.

3.2.2. Identifying Core Invalid Patents

The quality evaluation index system of failed patents is constructed from three levels, including legal, technical and economic, and the core failed patents are identified. The details of the patent quality evaluation index system are shown in Table 2.

Table 2. The core invalid patents quality evaluation index system.

Indicator Name	Calculation Method	Indicator Meaning
Legal quality indicator	$\overline{NC} = (NC_1 + NC_2 + \ldots + NC_n)/n$	A higher number of claims means a deeper understanding of the technology and a higher legal quality of the relevant technical patent documents.
Technical quality indicator	$\overline{CP} = (CP_1 + CP_2 + \ldots + CP_n)/n$	A higher number of positive citations means that the patent exhibits a higher level of technical sophistication.
Economic qualitative indicator	$\overline{SF} = (SF_1 + SF_2 + \ldots + SF_n)/n$	A higher number of homologues means a higher economic quality of the patent.

3.2.3. Extracting Technical Thematic Elements with BERTopic Model

Extraction of technical themes and technological innovation elements by BERTopic. Since BERTopic automatically identifies the number of technical themes, only the technical themes need to be named. When naming, expert opinion and the technological innovation elements contained in each topic need to be taken into account, thus creating the basis for subsequent innovative solutions in combination with TRIZ.

3.3. Innovation Solutions' Generation and Evaluation

As shown in Figure 2, innovation solutions' generation and evaluation mainly includes the following two steps.

3.3.1. Generating Innovative Solutions with TRIZ

On the basis of the aforementioned data collection and processing and the extraction of technical subject matter elements, this paper relies on TRIZ theory to assist in technology migration, enabling core technologies from other fields to be applied to the target product.

3.3.2. Evaluating Innovative Solutions with BWM

After generating specific innovative solutions, the above solutions need to be evaluated and ranked using the BWM. The specific steps are as follows [30,31]:

(1) Determine a set of criterion sets, and select the best and worst criteria CW in the criterion sets $\{c_1, c_2, \ldots, cn\}$.
(2) The numerical scoring used determines the degree of preference of the optimal criterion over all other criteria, and we constructed a comparison vector AB = $(a_{B1}, a_{B2}, \ldots, a_{Bn})$ in which the degree of preference of the optimal criterion compared to the criteria is indicated.
(3) The numerical scoring used to determine the degree of preference of all other criteria over the worst criterion, and the construction of a comparison vector AW = $(a_{1W}, a_{2W}, \ldots, a_{nw})^T$ in which the degree of preference of the criterion over the worst criterion is represented.
(4) A mathematical programming problem is constructed and solved to derive the optimal weights $\left(w_1^*,\ w_2^* \ldots, w_n^*\right)$.

4. Empirical Analysis

A slurry pump is a pump that can convey high viscosity, high density and abrasive materials and belongs to the category of centrifugal pumps [32]. A slurry pump is usually used in mining, metallurgy, electric power, coal chemical and other industries, and can convey various slurry media [33]. Because of its simple structure and stable operation, it has an important application in mining, metallurgy, electric power, the coal chemical industry and other industries [34,35].

However, the current range of applications for slurry pumps is, for the most part, used in mineral processing plants in the mining industry. The harsh working conditions of ore primary processing lead to a generally low service life of slurry pumps. Therefore, there is an urgent need to carry out the identification of technical opportunities in the field of slurry pumps.

In view of this, this paper takes slurry pump as an example to illustrate the application process of product innovation paths.

4.1. Identify Problems and Functional-Oriented Search

4.1.1. Identify the Target Product

In this paper, slurry pumps are selected as the target product for analysis to verify the feasibility and applicability of this product innovation path. Figure 3 shows the mainstream product.

4.1.2. Identify Problems with Function Analysis

The slurry pump to carry out functional analysis can have the following functions.

First, the conveying function. The slurry pump is mainly used to transport all kinds of materials to the designated location, in order to ensure that the materials are transported to a higher and farther location, it needs to be pressurised.

The second is the filtering function. In order to reduce the damage and blockage of the material to the subsequent equipment, it needs to be equipped with filters and other devices, so as to achieve the screening and filtering of the material.

Figure 3. Existing slurry pump.

The third is the stirring function. In order to prevent particles in the material from being deposited at the bottom and to ensure the homogeneity and stability of the material, equipment such as impellers need to be equipped for stirring.

4.1.3. Functional-Oriented Search

Based on the results of the above functional analysis, the corresponding search expressions are developed in conjunction with experts in the relevant fields in order to obtain new patents in other fields.

Taking the conveying function as an example, the standardised functional description is to pressurise and convey the material to a specified location, so the search expression is (material and pressurised conveying). The results are shown in Table 3.

Table 3. Patent search expression and search results.

Functions	Generalized Functions	Search Expressions	Number of Patents in All Areas
Transport	Conveying the material to the designated position	TS = (material AND conveying AND impeller)	2465

4.2. Identifying Core Invalid Patents and Extracting Technical Thematic Elements

4.2.1. Screening for Invalid Patents

Next, the invalid patents downloaded were screened according to their legal status and those that met the requirements were retained, resulting in a collection of 853 invalid patents relating to material pressurisation and conveying issues.

4.2.2. Identifying Core Invalid Patents

Further, a comprehensive evaluation of the three patent quality indicators at the legal, technical, and economic levels was conducted to identify the core invalid patents, and the relevant patent indicator values are shown in Table 4.

Obviously, an invalid patent with above-average legal quality, technical quality and economic quality indicators can be considered a core invalid patent.

4.2.3. Extracting Technical Thematic Elements with BERTopic Model

The patent text is divided into words, and the punctuation and common characters in the text are filtered out. Combined with the opinions of experts in related fields, a custom dictionary is built to prevent the technical terms unique to the slurry pump field from being incorrectly split.

Table 4. The related patent index value.

No.	Legal Quality Indicator	Technical Quality Indicator	Technical Quality Indicator
1	14	13	11
2	8	2	29
3	9	37	1
4	6	12	2
5	41	9	1
6	26	10	2
7	5	12	2
8	4	2	1
……	……	……	……
853	4	9	5
Average value	7.4	6.5	3

After data processing, this paper used BERTopic, a third-party library in Python, to extract the technical themes and technological innovation elements in the core invalid patent text. Initially, 20 themes were obtained. On this basis, the irrelevant themes were filtered out by combining the opinions of domain experts, and finally eight technical themes were obtained.

As the technical fields represented by each theme are clear and have a better clustering effect, the technical themes can be named according to the content of the technological innovation elements contained in each technical theme.

The specific conveying function patent technology themes and technological innovation elements are shown in Table 5.

Table 5. Technical topics and technical keywords by BERTopic.

Topics	Topic Tags	Technology Keywords
0	High temperature conveying	Thermocouples, insulation, water cooling systems, high temperature alloys, frequency control, heat loss
1	Pneumatic conveying	Injectors, pneumatic buffer tanks, separators, airflow handling, gas circuit design, sensor control
2	Gas conveying	Pressure vessels, piping systems, pumping station equipment, regulating valves, gas detection, safety testing
3	Mechanical conveying	Belt conveyors, spiral conveyors, drum conveyors, chain conveyors, vibratory conveyors, unmanned control
4	Hydrodynamic conveying	Pipelines, pumps, hydropower, regulating ponds, hydraulic turbines, hydraulic calculations
5	Magnetic conveying	Superconductor technology, intelligent control, permanent magnet motors, sensors, high-speed motion balancing, magnetic levitation
6	Vacuum conveying	Vacuum pumps, seals, material recovery, anti-clogging technology, automatic control, vibration
7	Gravity conveying	Bucket lifting, cylinder lifting, automatic control, sensor detection, conveyor line planning, safety protection devices

Further, by combining the opinions of domain experts, the technology innovation elements are deconstructed and dimensionalized, which enables the secondary categorisation of technology. The specific results are shown in Table 6.

Table 6. Conveyor function patent innovation dimension table.

Innovation Dimension	Elements of Technological Innovation
Structural dimension	Belt conveying, screw conveying, drum conveying, chain plate conveying, bucket lifting, barrel lifting, safety protection devices, thermocouples, pressure vessels, pumping station equipment, regulating valves, permanent magnet motors, sensors, seals

Table 6. *Cont.*

Innovation Dimension	Elements of Technological Innovation
Functional dimension	Ejectors, pneumatic buffer tanks, separators, water cooling systems, material recovery, sensor detection, frequency control, gas circuit design, sensor control, gas detection, safety detection, vacuum pumps, anti-clogging technology, vibration
Mechanistic dimension	Vibratory conveying, magnetic levitation, airflow handling, hydraulic calculations, superconductivity technology
Spatial dimension	Piping systems, conveying line planning, high speed motion balancing
Environmental dimension	Pipelines, pumps, hydropower, regulating ponds, hydraulic turbines, heat loss
Material dimension	High temperature alloys, thermal insulation
Human-machine dimension	Intelligent control, unmanned control, automatic control

4.3. Solving the Problem and Evaluating Solutions

4.3.1. Generating Innovative Solutions with TRIZ

After the innovation dimensions have been identified, the technological innovation elements in the innovation dimensions can be iteratively coupled with the inventive principles in turn, under the guidance of domain experts. The inventive principles that can identify technological opportunities through coupling can be retained to generate product innovation solutions.

This paper identifies the following four product innovation opportunities. The specific technology opportunities are described in Table 7.

Table 7. Technical opportunities for slurry pump conveying functions.

Innovation Dimension	Principle of Invention	Description of Technical Opportunities
Human-machine dimension (Intelligent control, unmanned control, automatic control)	15.Dynamicity 25.Self-service	A remote control system for slurry pumps is proposed, which combines cloud computing and Internet of Things technology to enable remote monitoring, data analysis and predictive maintenance of slurry pumps. At the same time, the operating experience of the human-machine interface is optimised to further improve the operability and ease of use of the slurry pump.
Functional dimension (Vibration, anti-clogging technology)	3. Local quality 30. Flexible shells or films	A system for enhancing the stability of slurry pumps is proposed. By introducing rotary commutators, pneumatic vibrators etc. to solve the problems such as blockage encountered by slurry pumps in the conveying process. At the same time, the noise and vibration of the slurry pump is reduced by using flexible connections, rubber shock absorbers, etc., thus improving its stability and reliability.
Structural dimension (Valve adjustment) Spatial dimension (Piping system)	1.Separation	A streamlining process is proposed. By streamlining and optimising unnecessary piping systems and valves in slurry pumps, pipeline resistance and energy consumption are reduced. At the same time, advanced materials and manufacturing processes are used to further reduce the gravity of the slurry pump itself in order to further reduce transport and installation costs.
Material dimension (Insulation materials) Human-machine dimension (Intelligent control)	3.Local quality 25.Self-service	Proposes an energy saving and emission reduction system. The conveying flow is optimised by intelligent control in order to reduce energy consumption and wastewater emissions. Insulation materials and energy efficient equipment are also used to reduce energy consumption and greenhouse gas emissions in the production process.

4.3.2. Evaluating Innovative Solutions with BWM

On the basis of generating the above four innovation options, it is also necessary to evaluate and rank the above options using the BWM.

Firstly, on the basis of the four-dimensional indicators such as development cost, novelty, feasibility and expected benefits, the BWM multi-criteria decision-making model can be applied to evaluate the four selected solutions on a trial basis as a whole;

Secondly, five experts are invited to identify the best and worst solutions as well as the remaining solutions under each indicator and compare them with the best and worst solution.

Due to space limitations, only an example evaluation of development cost indicators is presented in this paper, with the following steps:

Step 1: Determine the best and worst option. According to the experts' discussion, solution 1 is the optimal solution and solution 3 is the worst solution.
Step 2: The optimal solution is compared with the remaining solutions. Option 1 is compared with the remaining options separately and the result is BO = (1,3,8,4).
Step 3: The remaining options are compared with the worst option. Compare each of the remaining solutions with option 3 and the result is OW = $(9,7,1,3)^T$.
Step 4: Construct the mathematical planning problem and solve it. The following programming is solved and standard weights are determined via Lingo:

$$
\begin{aligned}
&\min \xi \\
&\text{s.t.} \\
&|\mathrm{w}_1 - 3 * \mathrm{w}_2| \le \xi \\
&|\mathrm{w}_1 - 8 * \mathrm{w}_3| \le \xi \\
&|\mathrm{w}_1 - 4 * \mathrm{w}_4| \le \xi \\
&|\mathrm{w}_2 - 9 * \mathrm{w}_3| \le \xi \\
&|\mathrm{w}_4 - 3 * \mathrm{w}_3| \le \xi \\
&w_1 + w_2 + w_3 + w_4 = 1 \\
&w_j \ge 0, j = 1, 2, 3, 4
\end{aligned}
$$

Solving the model leads to the following results: w_1 = 0.5388, w_2 = 0.2374, w_3 = 0.0457, w_4 = 0.1781.

Repeating the above steps and calculating the weights of the four innovative solutions under the three indicators of novelty, feasibility and expected benefits respectively, the final ranking of each solution can be obtained, as shown in Table 8.

Table 8. Evaluation and ranking results by programme.

	Development Costs	Novelty	Feasibility	Expected Benefits	Weighted Score	Ranking
Solution1	0.5388	0.4389	0.3876	0.6351	0.5001	1
Solution2	0.2374	0.2967	0.2581	0.3236	0.2790	2
Solution3	0.0457	0.0981	0.1413	0.2099	0.1238	4
Solution4	0.1781	0.1652	0.2987	0.3457	0.2469	3

It is easy to see that the four product innovation solutions proposed in this paper are, in descending order of priority, Solution 1, Solution 2, Solution 4, and Solution 3.

Similarly, the scenarios arising from the filtration and mixing problems of slurry pumps are shown in Tables 9 and 10.

Table 9. Technical opportunities for slurry pump filtering functions.

Innovation Dimension	Principle of Invention	Description of Technical Opportunities
Material dimension (Ceramic materials, polymer composites) Structure dimension (Filter)	3. Local quality 40. Composite materials	A design method to improve the lifespan of slurry pumps is proposed. By introducing the high-performance ceramics, polymer composites to improve their wear resistance and anti-clogging performance, thereby increasing their service life effectively.
Functional dimension (Cleanse) Structure dimension (Filter) Human-machine dimension (Sensor)	5. Consolidation 25. Self-service	A function for cleaning the slurry pumps is proposed. By introducing the specialized cleaning robots to regularly clean filters to reduce their impact on equipment. These robots can easily enter pump rooms or other hard-to-reach areas and use high-pressure water guns for cleaning. Additionally, it may be considered to integrate the automatic cleaning robots with sensors and control systems, so that they can identify the filters that need to be cleaned on their own and perform cleaning at appropriate times.
Function dimension (Electron beam, ultrasonic waves)	3. Local quality 5. Consolidation	A filter system is proposed. By introducing electron beam emitters to process the slurry inside the pump. Electron beams form efficient chemical reactions by interacting with water molecules, producing free oxygen ions and killing bacteria, viruses and other microorganisms. Similarly, ultrasonic sensors can be used to generate ultrasonic waves to disperse particulate matter and suspend matter into smaller particles and more uniform mixtures. This can improve filtration efficiency and reduce the risk of equipment damage and blockage.

Table 10. Technical opportunities for slurry pump stirring functions.

Innovation Dimension	Principle of Invention	Description of Technical Opportunities
Structure dimension (Blade)	1. Segmentation 15. Dynamicity	An adjustable mixing blade design system is proposed. By introducing the electric motor control system to achieve automatic adjustment, thereby improves mixing efficiency and operational convenience. Additionally, a multi-stage adjustable mixing blade design can be considered. This design can divide the mixing blades into multiple parts, each of which can be independently adjusted to meet the mixing requirements of different materials.
Structure dimension (Blade) Function dimension (Ultrasonic waves)	1. Segmentation 5. Consolidation	A swirling mixing technology is proposed. Introducing special mixing blades or a multi-stage cyclone to rotate rapidly within the pump and separate the suspended material through centrifugal force, achieves a more efficient and thorough mixing effect. Additionally, the swirling mixing technology can also be combined with other technologies to improve its effectiveness and stability. Ultrasonic waves can be used to enhance the stirring effect.
Function dimension (Stir) Human-machine dimension (Sensor)	5. Consolidation 15. Dynamicity	A monitoring and analysis system is proposed. By introducing multiple sensors and instruments to monitor the flow, temperature, concentration, and pressure parameters of materials. Based on different material and process characteristics, appropriate control algorithms and models can be selected for adaptive adjustment to achieve the best stirring effect.

5. Conclusions

Technological innovation can provide a scientific basis for decisions to accelerate the pace of innovation, achieve technological catch-up and maintain a strategic competitive high ground for enterprises. In recent years, research around patents has gained importance and developed rapidly, helping enterprises to break technology blockades and industry barriers.

However, the current patent-based technological innovation suffers from problems such as neglecting the usable value and application potential of failed patents. To address these problems, this study proposes a new approach to improve on previous methods.

Firstly, unlike previous scholars who mainly face valid patents for product innovation opportunity identification, the path constructed in this paper can be better oriented towards invalid patents for product innovation design.

Secondly, we add the step of identifying core invalid patents through multi-indicator evaluation to the FOS-based full-domain patent search of the proposed target problem.

Finally, we extracted technical subject matter elements based on BERTopic and further assisted with cross-domain technology migration work through TRIZ theory tools.

Through a case study of a slurry pump, we demonstrate the feasibility and effectiveness of the proposed approach.

5.1. Implications for Theory and Practice

The constructed pathway provides a broad understanding of product innovation opportunity identification across multiple domains; therefore, this study has novel theoretical and practical implications.

5.1.1. Theoretical Implications

Firstly, we expand the field of invalid patenting research. The thesis explores the identification of product innovation opportunities from the perspective of invalid patents, combining FOS and BERTopic.

This provides new perspectives and methods for the expansion of the field of failure patent research. The approach constructed allows for better exploitation of the application value and potential of failed patents, unlike previous researchers who have mainly dealt with recently published patents.

This is one of the few product innovation pathways for constructing lapsed patents in current research. The final results show that the path is well suited to the study of lapsed patents.

Secondly, we enrich the product innovation theory. By building on the perspective of invalid patents, the thesis proposes a new approach to identifying product innovation opportunities.

The path innovatively adds the evaluation and identification step of core failed patents to the FOS-based domain-wide patent technology search, thus effectively solving the problem of cumbersome and difficult cross-domain patent analysis and greatly improving the novelty and efficiency of innovation.

The method uses the BERTopic model to extract the technical subject matter elements of a patent, thus effectively solving the problem of existing patent analysis over-relying on expert knowledge to obtain technical information from a large number of patents, which is both unobjective and time-consuming and inevitably leads to errors in the structure of patent analysis.

5.1.2. Practical Implications

Firstly, we have improved the efficiency of product innovation. Using the FOS and BERTopic, the product innovation opportunity identification method proposed in the thesis can help companies and research institutions to more accurately identify innovation opportunities in invalid patents. This helps to improve the efficiency of product innovation, reduce waste of resources and promote the competitiveness and market position of firms.

Secondly, we facilitate technology transfer and transformation. By identifying innovation opportunities in invalid patents, the findings of the thesis can help the implementation of technology transfer and transformation. The technological resources contained in invalid patents can be reused to facilitate technology transfer and transformation, promoting the industrialisation and commercialisation of technological achievements.

Again, we provide decision support tools: the product innovation opportunity identification method proposed in the thesis can be used as a decision support tool to help companies and research institutions make more informed choices in product development and innovation investment decisions. This helps to reduce innovation risk and improve the accuracy and success of decisions.

In addition to the above implications, the method proposed in this paper can also help small and micro enterprises that lack the resources to develop new technologies or large enterprises that wish to develop higher level technologies first and thus capture the market. Researchers can use this approach to discover technologies or methods in other fields from invalid patents and generate new ideas to solve their problems.

The constructed pathways thus provide companies with precise insight into trends in embodied technology areas and optimise the allocation of resources for technological innovation as a scientific basis for decision-making.

5.2. Limitations and Future Research Directions

Despite these contributions, there are still some limitations to this study.

Firstly, this paper has only conducted research on technologies related to the slurry pump product field, and future research needs to be further oriented towards products and technologies in multiple fields in order to enhance the universality of product innovation paths.

Secondly, the core invalid patent evaluation index system constructed in this paper is not comprehensive enough, and further consideration should be given to developing a more comprehensive evaluation index system to evaluate its value in order to enhance the evaluation index system in future research.

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