Research on innovation design of corn cutting platform based on evolution of technology system

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Abstract. In order to accurately predict the future direction of corn cutting platform technology and rapidly develop a new generation of technologies and products, it is crucial to determine the current position of the corn cutting platform technology in the life cycle. Corn cutting platform had problems such as inefficient design, relatively high purchase costs, and short life. After quantitative and qualitative analysis of patents related to corn cutting platform technology, the S-curve law of technical system evolution theory was used to predict that the current corn cutting platform technology is in a recession period in the S-curve. In this period the super-system evolution law should be used in the innovative design of the corn cutting platform. Thereby the design efficiency of the corn header is improved. The causal chain analysis method was used to analyze the reasons for the high cost of the corn cutting platform. It is inferred that the above problems can be solved from the "single corn cutting platform function" and "too long corn cutting platform idle time". The corn cutting platform that harvests both grain corn and silage corn was derived by applying the technical contradiction method and the super-system evolution rule.

1. Introduction
The silage corn cutting platform is the main tool for farmers to harvest silage corn. Its main function is to crush and collect silage corn plants. The stem and ear harvesting corn cutting platform is the main tool for farmers to harvest grain corn ears and straw. Its main function is to harvest corn ear while harvesting corn silage. When the silage corn is harvested using the stem and ear harvesting corn header the ears of the silage corn are picked up by the picking device without being silaged. This causes a serious waste of silage. Therefore silage corn cannot be harvested from the stem and ear harvesting corn cutting platform [1]. In order to improve the ideality of the corn cutting platform this paper will carry out innovative design of the corn cutting platform based on technical system evolution theory. Making accurate judgments on the maturity of the current corn cutting platform technology is an important prerequisite for predicting the evolution direction of the corn cutting platform using technical system evolution theory.

2. TRIZ theory
TRIZ theory believes that product improvement and technological innovation in any field are the same as biological systems. There are processes of production, growth, maturity and aging. Therefore mastering technical system evolution theory has important implications for the development of new products [2].
2.1. S-curve
The evolution of each technical system goes through four phases on the S-curve: infancy, growth, maturity and recession, as shown in Figure 1. The S-curve completely describes the life cycle of a technical system. Analyzing S-curve of technological development helps to understand the maturity of the technology system and assist the company in making appropriate research and development decision.

2.2. Technical system maturity forecast
Altshuller found that the growth of technology is generally represented by an S-curve. The segmented S-curve is used to represent the growth process of the technology, the relationship between patent grade and time, the relationship between the number of patents and time and the relationship between profitability and time [3], as shown in Figure 2.

In the conceptual design phase the principle of innovation is sought for the product. This new way of working is called the original understanding. In the TRIZ theory the original understanding is divided into five levels, as shown in Table 1 [4]. According to the five original understandings of the six attributes in Table 1 the grades of the Corn header related patents were evaluated.

Table 1. A slightly more complex table with a narrow caption.

| Original solution level | Design task selection | Search concept selection | Data collection | Solution search | Production plan | Practical application |
|-------------------------|-----------------------|--------------------------|----------------|----------------|-------------------|----------------------|
| 1                       | Solve existing tasks  | The concept to search already exists | Existing data | Use existing methods | Using a molded design | Manufacturing existing products |
| 2                       | Choose one of the design tasks | Choose one of concepts | Collect data from multiple sources | Choose one of the partial solutions | Choose one of a set of designs | Slightly improved product |
| 3                       | Change the initial design task | Adjust the concept of search to adapt to new design tasks | Adjust the collected data to adapt new design tasks | Obtained by modifying an existing solution | Modify existing design | New design product |
| 4                       | Discover new design tasks | Discover new search concepts | Gather new data related to new tasks | Discover new solutions | Discover new designs | Innovative design of products in new ways |
| 5                       | Found new problems | Discover new methods | Gather new data related to new issues | Discover new concepts | Improve the constructive design | Transform existing systems with new working principles |

Table 1. A slightly more complex table with a narrow caption.
2.3. S-curve and technological system evolution rule
In the process of applying TRIZ theory to solve problems analyzing problems is an indispensable part. Commonly used methods for analyzing problems include resource analysis, functional analysis, contradiction analysis and causal analysis. Problem analysis is the key to turning practical problems into TRIZ problems. Resource analysis is the necessary foundation for solving difficult and complex problems. Within any unsatisfactory and problematic technical system there are resources to solve the problem. Functional analysis is a very important step in improving the system's innovation process. First of all, it is necessary to find out the main functions of the system is necessary and then improve this function; Secondly find out the harmful, insufficient and excessive functions of the system in order to find out the problem of the system and then completely solve the problem. Contradictory analysis is an important means to improve the technical level of the system. Finding engineering parameters to improve and deteriorate can pave the way for resolving conflicts. In the causal analysis the problem is the result and the cause of the problem is found. Then based on these reasons the reasons for the above results are listed.

2.4. Analyse problem
The frequency of application of the eight technological system evolution rules in the four periods of the S-curve is different. The evolutionary rule that is primarily used in infancy is the completeness law; The evolutionary rule that is mainly applied in the growth period is the subsystem imbalance law, the dynamic evolution law and the improving ideality law; The evolutionary rule that is mainly applied during the maturity period is to the microscopic evolutionary law; The evolutionary rule that is primarily used during the recession is the super-system evolution law. Until you can't find the next reason or reach non-technical reasons such as natural phenomena, systems, regulations, costs, etc.

2.5. Solving problems
The methods commonly used to solve problems in the process of applying TRIZ theory are technical contradiction, physical contradiction, material-field model, How to model and technical system evolution rule. To better describe the contradictions TRIZ theory proposes to use 39 general engineering parameters to generalize and standardize conflict descriptions. This method is used to transform the contradiction in actual engineering design into general or standard technical contradiction. In order to better solve the contradictions in the design TRIZ proposed 40 invention principles. Applying a contradiction matrix consisting of 39 general engineering parameters and 40 invention principles can quickly and easily resolve technical contradictions. Physical contradiction
refers to the technical requirements of the two opposite natures of the technical system. The principle of separation provides a solution to physical contradictions. Separation principles include spatial separation, time separation, condition-based separation and separation of whole and partial. The material-field analysis method is the basis of the TRIZ theory which states that an existing function must consist of three basic components (two substances and one field). A substance can be any form of part and a field is an energy form. In the classic TRIZ theory Altshuller proposed the application of the How to model combined with the scientific effect knowledge base for invention and creation. After combining the actual problem with the 30 standard How to models common problems in engineering are solved by applying 100 scientific effects. Through the analysis of the world patent library Altshuller discovered and confirmed the trend of technological evolution in technology namely technical system evolution theory. Moreover he also found that the evolutionary rules summarized in an engineering field can be realized in another engineering field. Technical system evolution theory is transitive. Thereby technology prediction system is formed in TRIZ.

3. Innovative design of corn cutting platform

3.1. Technical route

Combining the technical system maturity prediction with the TRIZ problem solving process, the technical route of the corn cutting platform innovation design is obtained [5], as shown in Figure 3.

![Diagram of the technical route of corn cutting platform](image)

Figure 3. The technical route of the corn header innovation design.

3.2. Technical route

Through quantitative analysis of the "corn cutting platform" related patents the number of annual applications for corn cutting platform in China from 1989 to 2018 was statistically obtained as shown in Table 2. Through qualitative analysis of the "corn head" related patents, the relevant patents were scored using the original understanding in the TRIZ theory. The annual patent scores were averaged. And the average annual score of the corn header related patents in China from 1989 to 2018 is obtained as shown in table 2. The relevant patent (patent application number: CN90221041) of the
1990 corn cutting platform was used as an example for rating [6]. The specific operation was:(1) The domestic elastic-toothed drum type picker and the foreign belt-type picker were not suitable for the high-bar corn crop which was "Found new problems". And the attribute A is rated 5 points. (2) The elastic tooth with high elasticity and strong picking ability harvested the high-bar corn crop which is a "Discover new methods". And the attribute B was rated 5 points. (3) The pick-up drums collected in China and the foreign-made belt pickers had a low pick-up rate for corn and other high-altitude crops. And the attribute C was rated 5 points. (4) The method of elastic picking was used as “Discover new concepts". And the attribute D is rated 5 points. (5) Increasing the function of picking up the high-crop crops was a "Improve the constructive design". And the attribute E is rated 5 points. (6) The application of the modified working principle was shown in the schematic diagram of the patent. And the attribute F is rated 5 points. The original understanding of this patent was \((\frac{5+5+5+5+5+5}{6})=5\). So a rating of 5 was given. There was only one patent for the corn head in 1990 so the average value of the patent grade in 1990 was 5. The same can be used to evaluate the average of the patent grades for the remaining years [7].

From the relationship between time and the number of patents the patent application curve of corn cutting platform in China was obtained as shown in Figure 4. From the relationship between time and the average annual score of the patent the patented technical grade score curve of China corn cutting platform from 1989 to 2018 was obtained as shown in Figure 5. In Figure 4 protrusions appeared during the ascent in 1998, 2008, and 2012. The curve in Figure 5 showed protrusions during the descent around 1998. Comparing Figure 2, Figure 4 and Figure 5 it can be concluded that the technology is in a recession period and the innovative design of the corn header should be selected to the super-system evolution law [8].

![Figure 4. 1989-2018 China corn cutting platform patent technology application volume curve.](image)

![Figure 5. 1989-2018 China corn cutting platform patent technology grade score curve.](image)

| Time | Quantity | Grade | Time | Quantity | Grade |
|------|----------|-------|------|----------|-------|
| 1989 | 2        | 5     | 1999 | 12       | 4.49  |
| 1990 | 1        | 5     | 2000 | 5        | 4.71  |
| 1991 | 1        | 4.63  | 2001 | 10       | 2.93  |
| 1992 | 1        | 4.37  | 2002 | 7        | 2.67  |
| 1993 | 1        | 4.31  | 2003 | 5        | 2.22  |
| 1994 | 0        | 4.09  | 2004 | 13       | 2.18  |
| 1995 | 6        | 4.02  | 2005 | 23       | 1.76  |
| 1996 | 1        | 3.98  | 2006 | 26       | 1.64  |
| 1997 | 6        | 4.15  | 2007 | 51       | 1.30  |
| 1998 | 7        | 4.25  | 2008 | 5        | 1.30  |

Table 2. Summary of patent information on corn cutting table.
3.3. Analyse problem
The annual planting area of corn in China had reached 31 million hm². The three major maize growing areas mainly in the northern region, the Huanghuaihai region and the southwestern hilly region accounted for about 80% of the country's planted area. The annual average corn planting area in the southwest hilly area was above 4.67 million hm². Maize harvesting had been largely achieved in most plain areas, with corn cutting platforms being an important part of corn harvesting machinery. On the patent search website of the State Intellectual Property Office the patent search was carried out with the keyword "corn cutting platform". And 1237 pieces of related patent information from 1989 to 2018 were retrieved [9]. However no one had made an accurate judgment on the maturity of the current corn cutting platform system by analyzing the patents related to the corn cutting platform. In order to make an accurate judgment on the evolution direction of the corn cutting platform technology system and the changing trend of the corn header market it is necessary to judge the maturity of the corn cutting platform technology system by analyzing the patent accurately.

For farmers the price of corn was higher. Corn harvesting machinery in hilly areas was less used. The undulating terrain and smaller fields in the hilly areas limit the use of large and medium-sized corn harvesting machinery. The price of corn in 2013-2018 had been decreasing year after year resulting in a decrease in the area planted with grain corn. However silage corn feed had been in short supply in 2013-2018 resulting in an increase in the area planted with silage corn. Taking Shandong Province as an example silage corn began to be harvested in mid-August and the best harvest period lasted about 20 days. Grain corn is harvested in mid-late September. It can be seen that the harvest period of silage corn does not coincide with the harvest period of grain corn. Based on two harvesting seasons per year the silage corn cutting platform for harvesting silage corn is used for about 40 days a year. The corn cutting platform for harvesting grain corn is not used for more than two months a year. Both corn cutting platforms have been idle for more than 300 days a year which inevitably causes problems such as rust on the corn header. In summary, the reason for the high price of the corn cutting platform is shown in Figure 6.

![Figure 6. Analysis of the reasons for the high price of corn cutting platform.](image)

3.4. Solution

3.4.1. Application of technological system evolution theory. Taking into account the above factors the corn cutting platform is innovatively designed by the super-system evolution law. The specific method was to divide the silage corn cutting platform and the stem and ear harvesting corn cutting platform according to the functional module. It can be concluded that the stem and ear harvesting corn cutting platform has more popping modules and ear conveying modules than the silage corn headers, as shown in Table 3. The silage corn cutting platform had the ability to harvest ears using a non-homogeneous integration approach to the super-system evolution law. An earing module and an ear
delivery module were added for the silage corn cutting platform. A silage corn cutting platform with a picking function was obtained.

| Header type                  | Silage corn cutting platform | Stem and ear corn cutting platform |
|------------------------------|-----------------------------|-----------------------------------|
| Smashing module              | ✓                           | ✓                                 |
| Feed module                  | ✓                           | ✓                                 |
| Draw cylinder                | ✓                           | ✓                                 |
| Picking module               |                             | ✓                                 |
| Ear delivery module          |                             |                                    |

### 3.4.2. Applying technical contradiction

It can be seen from Figure 6 that "single corn cutting platform function" and "excessive header idle time" correspond to "35 applicability and versatility" and "16 stationary object action time" in the technical contradiction table. The general engineering parameters for improvement were "35 applicability and versatility". The deteriorated general engineering parameter was "16 stationary object action time". By querying the contradiction matrix table the corresponding invention principles were "2 separation" and "16 unreached or exceeded effects" [10].

- **Engineering parameters:**
  - 16 stationary object action time: The time and service period for the object to complete the specified action. The time between two misoperations is also a measure of the duration of action.
  - 35 applicability and versatility: The ability of an object or system to respond to external changes or to the ability to apply under different conditions.

- **Principle of invention:**
  - 2 separation: (1) Separate the "interference" part of the object. (2) Separate the key parts of the object.
  - 16 does not reach or overwork principle: If it is difficult to achieve the desired effect completely, slightly not achieving or slightly exceeding the expected effect will greatly simplify the problem.

"2 separation" of the invention principle was applied to the design of a silage corn cutting platform having a picking function. The specific approach is: After the picking module and the ear conveying module are installed as a whole on the silage corn cutting platform the mature grain corn can be subjected to the stem and ear harvesting operation; After removing the whole of the picking module and the ear conveying module the silage corn was harvested using a silage corn cutting platform.

### 3.4.3. Advantages of the evolved corn cutting platform

1. The corn cutting platform can perform both harvesting of silage corn and harvesting of grain corn. The use time of the corn cutting platform is extended. Thereby reducing the idle time of the corn cutting platform and slowing the rust of the corn cutting platform.
2. The removable design of the picking module and the ear conveying module enables the cleaning module and the ear conveying module to be more comprehensively maintained. Thereby extending the service life of the corn cutting platform.
3. A corn cutting platform has the function of harvesting two kinds of corn. The ideal for corn headers is improved.

### 4. Summary

Applying TRIZ theory can help designers systematically and regularly solve problems encountered in product design research. Compared to traditional methods technology-based systems evolution theory can significantly improve the efficiency of system innovation and can be applied to the development and improvement of many other products. The causal analysis method can concisely and accurately represent the causal relationship of things and then identify and discover the causes and improvement methods of the problems. In order to improve the ideality of the product, comprehensive application technology evolution rules, contradiction matrix and other tools can materialize the concept. Higher quality innovative solutions are obtained. Product development cycle is significantly shortened.
Acknowledgments

Fund Project: 2017 Shandong Province Agricultural Machinery R&D and Innovation Plan Funded Project (2017YF004–10).

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