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Research on IFR of Technological Evolution Bifurcations

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Abstract

Idealization is a powerful tool in TRIZ, and it plays an important role in innovation processes. In the fierce market competition, in order to adopt new technology and make their product approach to ideal product, enterprises spare no effort to improve the degree of product's idealization. At the bifurcation points of product technology evolution, the ideal result that customers need changes, but because of the existence of conventional thinking and market competition, engineers always engage in designing according to the original target ideal result, finally the technology innovation opportunities are lost, so it is of great significance to study the Ideal Final Result (IFR) at the bifurcation points. According to different innovation processes of S-curves, the IFR for product's technology evolution bifurcations are divided into four classifications, Incremental Innovation Ideal Final Result(IFR_II), Radical Innovation Ideal Final Result(IFR_RI), Low-end Disruptive Innovation Ideal Final Result(IFR_LDI) and New-market Disruptive Innovation Ideal Final Result(IFR_NDI). Product's technology system consists of several technology sub-systems, correspondingly, ideal product is made up of several idealized technology sub-systems. It is the objective of product design that realizing the idealization of technology subsystem through innovation design, however, because the presence of conflicts and design constraints among technology sub-systems, the design aim for realizing ideal final results of each sub-system is almost impossible. Therefore, in designing processes, engineers always give priority to several mainstream technology sub-systems and realize their idealization first. This paper decomposes IFR into several ideal results of sub-systems based on a technical system decomposition method, researches a process of technology evolution and a changing process of sub-systems' ideal results, determines evolution bifurcations' direction of technology systems through the combination of the sub-systems' ideal results and then realizes the technology forecasting at the evolution bifurcation points.

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Keywords: Technological evolution bifurcation, IFR, Incremental Innovation, Disruptive Innovation, Radical Innovation;

1. Introduction

In TRIZ, Ideal Final Result (IFR) plays an important role in the process of problem definition and solving. In many cases, developing a clear statement of the IFR will lead directly to a solution to the problem [1].

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Idealization includes ideal system, ideal process, ideal resources, ideal methods, ideal machines, ideal substances, etc. [2]. Idealization includes partial idealization and global idealization, the partial idealization process has four kinds of patterns, strengthening, reduction, generalization and specialization; global idealization has three kinds of patterns [3], they are function ban, system ban and change of principle respectively.

Technical system is the realization of function. During the process that realizing the customers' needs for function, any system will produce negative effects. The ideality of technical system is directly proportional to the sum of effective function, and is inversely proportional to the sum of unavailable function, and improving the ideality of system continuously is the goal of product innovation [4].

The ultimate goal of technology evolution is the ideal final result [5-6], but there are multiple complex technology bifurcations in the process of product evolution. The formation of these technology bifurcations is largely caused by variation of ideal result, so it is of great importance that researching on technology evolution bifurcations.

In the 70s, inspired by the biology evolution theory, R.Nelson and S.Winter established the innovation evolution theory [7]. Nelson hold the view that an evolutionary system should include innovation mechanism, selection mechanism and system searching capability etc.

Ziman carried on in-depth study on the similarity of technology evolution and biology evolution, he supposes that technology innovation can be seen as a process of "ecology", in which a large number of different types of entities, physical, social, and cognitive, they interact and co-evolute with mutual adaptation among them [8].

G.S.Altshuller created TRIZ, in which the theory of technology system evolution [9] is one important theory, and he presented that the evolution of technology system is not at random, all the systems evolve toward the final ideal result, besides, technical Systems are driven by objective laws [10], and they impact in the design process [11]. Many scholars enrich technology evolution theory afterwards, e.g. Evolution of Technique (ET) introduced by Savransky [12], Guided Technology Evolution(GTE) by Fey and Rivin[13], Directed Evolution (DE) by Zusman [14], The law of system evolution presented by Petrov [15].

Zlotin and Zusman [16] established a model of technology evolution bifurcations, he defined the situation of evolution bifurcation points as random state, nevertheless, he did not solve technology forecasting problem at the points of bifurcation.

Therefore, on the basis of the research on technology evolution bifurcations, the paper achieves the technology forecasting at bifurcation points based on variation of ideal result.

1. IFR of technology system

Technical system consists of many technology sub-systems [17], for any complex product, technology sub-systems can also be decomposed level by level, that is to say every technology sub-system is made up of multi-subsystems, however, it is different from function decomposition [18-19], the additional constraints [20] of sub-systems should also be taken into consideration. The ideality of technology system is decided by the ideality of each technology sub-system and the ideality of additional constraint system comprehensively. It means that one ideal product should be not only have ideal technology sub-system, but also have ideal constraint system (See Fig.1).

In order to analyze the degree of idealization conveniently, the ideality of technology system can also be shown as equation 1:

$$I = \sum_{1}^{n} K_n I_{Fn} + \sum_{1}^{m} K_m I_{Cm} \quad (1)$$

I — the ideality of technical system, I_F —ideality of the technical subsystem functions, K —weighting factor, I_C — the ideality of additional constraints.

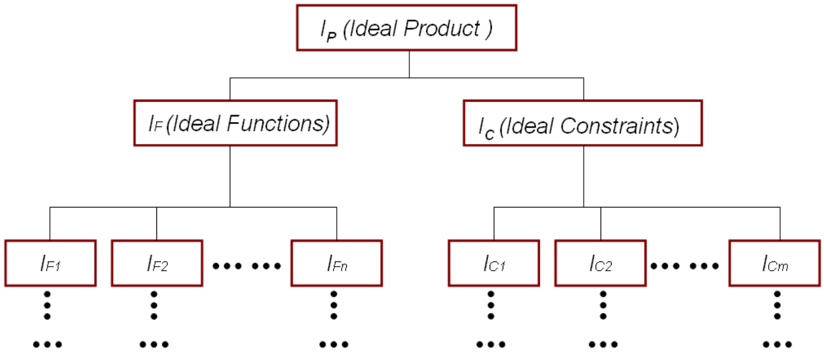

Fig.1.Technology system formation of ideal product

The ideal result of technical system include each technical system's ideal result (I_{Fn}) and additional constraint system's ideal result (I_{Cm}). For the description of one product's ideal result, it can be described by any combination of elements in set $\{I_{F1}, \ldots, I_{Fn}, I_{C1}, \ldots, I_{Cm},\}$. When there is only one sub-system realizes ideal result, any element alone in the set$\{I_{F1}, \ldots, I_{Fn}, I_{C1}, \ldots, I_{Cm},\}$ can constitutes the system's ideal result, so the ideal result of system can be the following possible situations$\{I_{F1}\},\{I_{F2}\}, \ldots, \{I_{Fn}\}, \{I_{C1}\}, \ldots, \{I_{Cm}\}$, according to the mathematic algorithm of permutation and combination, the number in this situation is C^1_{m+n}. When there are only two elements in set$\{I_{F1}, \ldots, I_{Fn}, I_{C1}, \ldots, I_{Cm},\}$ are realized, then for the system, it can have the following possibilities,$\{I_{F1},I_{F2}\}, \ldots \{I_{F1},I_{Cm}\},\{I_{F2},I_{F3}\},\ldots\{I_{F2},I_{Cm}\},\ldots\{I_{C(m-1)},I_{Cm}\}$,the number of this case is C^2_{m+n}. With reference to the same principle, the description possibilities of ideal result for one technical system, the total number is $C^1_{m+n}+C^2_{m+n}+C^3_{m+n}+\ldots C^{m+n}_{m+n}$, equally 2^{m+n}-1 (See equation 2).

$$K_I = 2^{m+n}-1 \qquad (2)$$

K_I - *the total number of ideal results.*

Just because there are different descriptions of the ideal result for one product, so each product has its diversity, at the same time, every product owns different innovation opportunities. During the process of product design, the structure of general function is composed of multiple function structure of sub-systems, correspondingly, product technology is made up of multiple technology sub-systems. Ideal product is usually made up of ideal technology sub-systems, and realizing idealization of each technology sub-system through innovative design is the ultimate objective of product design. However, because the existence of conflicts and design constraints among technology subsystems, the ideal product is almost impossible to achieve, hence, during the process of product design, engineers always give priority to the idealization of mainstream technology subsystems, this is the idealized design characteristic of sustaining innovation.

2. Technological Evolution Bifurcations

Ideal final result is the ultimate objective of technology evolution, all the routes of technology evolution stretch toward the ideal final result [21], but in the process of technology evolution, the evolution routes may generate bifurcations. According to definite routes of technology evolution, the forecasting of technology can be accomplished, actually, all the technology evolution routes in the past have characteristics in common: they are concluded through the evolutionary history of technology which has already happened, and then be applied to forecast the next technology state. Though the existing methods can only predict the adjacent technology state on the same continuous S-curve, for the mutations of technical route occurring on different S-curves, the forecasting is difficult to predict effectively. With the fierce competition in the market, high class in effective technology innovation usually belongs to the latter situation.

In order to predict the potential state at the points of technology evolution, it is needed to classify the technology evolution direction on these points. The process of technology evolution is usually shown by a series of head-tail S-curves. It is constrained to be the S-curve track, and the corresponding bifurcations of technology evolution path determine the classification of innovation.

As shown in Fig.2, the technology evolution bifurcation from B to C happens on the same S-curve, its innovation process is the problem of resolving local conflicts and improving performance, and it depends largely on the path, this is called Incremental Bifurcation (IB).

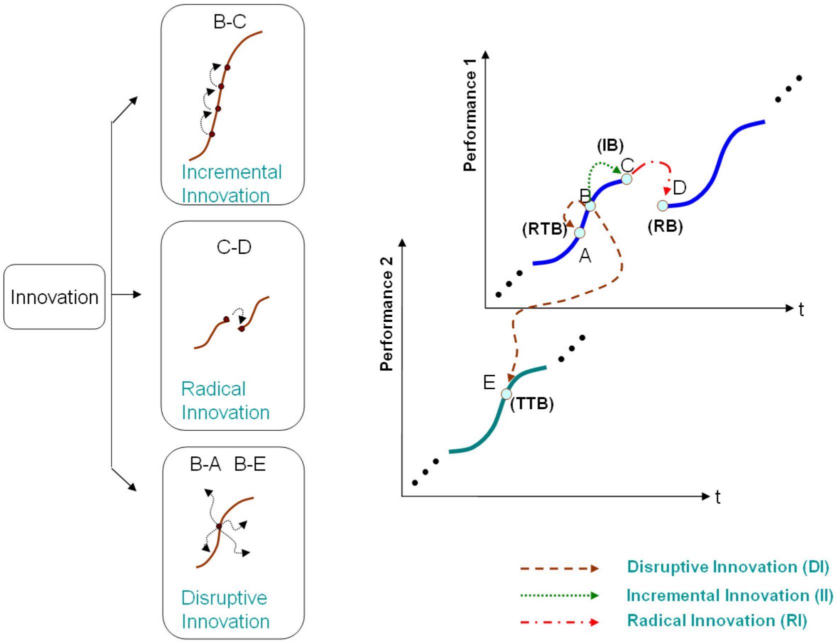

Fig.2 .IFR of Technological Evolution Bifurcations

When products evolve to the exit stage, though the improvement of existing technology reaches its limit, the technology can not satisfy the market's needs, now the technology innovation[22] from C to D happens and the new technology is developed at this moment, this is called Radical Bifurcation (RB), it is shown as sequential head-tail link of adjacent S-curves.

Disruptive Innovation (DI) happens at the maturity stage of S-curve, one case is that the short-term retrogression of technology evolution, it is shown as the evolution bifurcation from B to A in Fig. 2, this is called reverse trajectory bifurcation (RTB); the other case is the jumping from one maturity stage to another between different S-curve families, it is shown as the evolution bifurcation from B to E in Fig. 2, this is called Transfer Trajectory Bifurcations (TTB).

3. IFR on Technological Evolution Bifurcations

3.1. IFR driven by Need

Driving force of products' technology innovation is derived from customer needs, so the ideal description of product is determined by customer needs. Driven by them, the ideal result is also changing. Customer needs change in both space dimension and time dimension. Spatially, the needs from different customer groups are different, the number of customers in this group changes all the time, and it leads to the degree of customer needs for product's performance changes. In terms of time dimension, the need of the same customer group is changing by time, in other words, the needs also evolve [23]. The changes of needs result in the changes of product's ideal result, and then bring about the generation of technology evolution bifurcations.

3.2. IFR concept classification

In view of the difference of technology evolution bifurcations[24], IFRs are divided into the following classifications:

- Incremental Innovation Ideal Final Result (IFR_II)

The generation of IFR_II is owing to the improved needs which are from the mainstream market customers for product's main function, moreover, the needs can be realized by the improvement of the existing technology system. It means that there is no need to introduce resources outside of the system to realize these needs. IFR_II makes technology evolve along the existing S-curve, and cause Incremental Bifurcations (IB) of technology evolution.

- Radical Innovation Ideal Final Result (IFR_RI)

IFR_RI is also owing to the improved needs from the mainstream market users for product's main function, but as the resources within the system have run out, it is needed to introduce new technology to realize radical improvement for main function. IFR_RI gives rise to the change from the existing S-curve to the neighbouring S-curve, and then cause Radical Bifurcations (RB) of technology evolution.

- Low-end Disruptive Innovation Ideal Final Result (IFR_LDI)

IFR_LDI derives from the specific requirements of low-end customers for the product. For these customers, the main function of the existing product is beyond their actual needs, customers expect that the main function of the product can be cut, so as to realize the reduction of price or improvements of other functions. IFR_LDI results in the decrease of product's main function, and it is characterized by the short back of product's technology evolution, the bifurcations in this situation are called Reverse Trajectory Bifurcations (RTB).

- New-market Disruptive Innovation Ideal Final Result (IFR_NDI)

IFR_LDI derives from the specific requirements for product which are from special customer groups. For special customers, the main function of the existing product has satisfied their actual needs, but some other functions of the product are far from meeting their needs. Driven by the needs of these customers, new ideal result should be significantly improved in part of auxiliary functions. IFR_NDI changes the distribution of main and auxiliary function in the technical system, and it makes the ideality of auxiliary functions' technology sub-system plays a leading role in the IFR of products. This behaves as the transfer trajectory bifurcations (TTB) at the point of technology evolution bifurcations, and eventually achieves the transformation of the S-curve in different coordinate systems.

3.3. Technology Forecasting Based on IFR

Any product is in an intensely competitive market, the mainstream function of products is the focus of market competition. IFR of the product usually behaves as the idealization degree of mainstream function, this is the main direction of product's evolution, on the S-curve, it is shown as the technology evolution along the original S-curve. However, in addition to the main function, any product has many auxiliary functions and various kinds of constraints, the change of these factors is likely to cause bifurcations of product technology evolution and form new technology evolution routes, eventually generate new IFR. The generation of new IFR makes a new prediction method of technology.

As is shown in Fig.3, the technology forecasting procedures of evolution bifurcation points based on IFR are as follows.

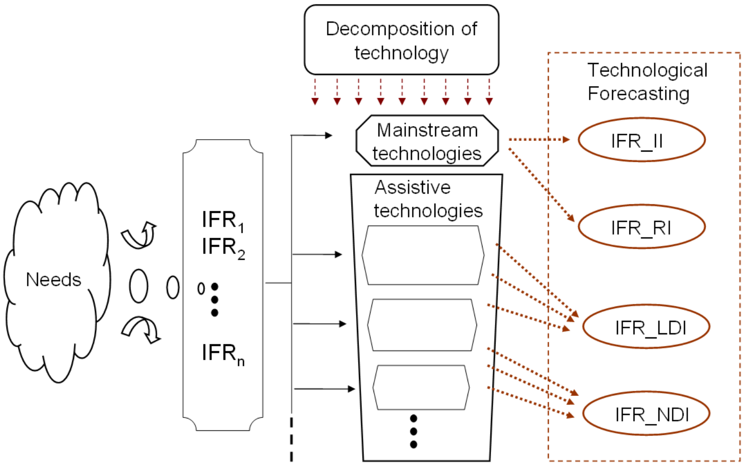

Fig.3. Technology Forecasting Model Based on IFR

Step1: Survey of customer needs. Engineers collect customers' various requirements, and form a list.

Step2: Description of IFR. Based on the new needs of customers, according to the definition of ideality, engineers define product's ideal result in this customer group.

Step3: Decomposition of product's technology system. Engineers recognize technology sub-systems and distinguish mainstream technology from auxiliary technology.

Step4: According to the decomposition result of technical system, the classification of IFR (IFR_II, IFR_RI, IFR_LDI and IFR_NDI) is acquired by comparison of the current state of product's technology sub-system with IFR of each user group.

- If the mainstream technology sub-system needs to be strengthened, and there are resources can be applied to realize it, then we define this kind of IFR as IFR_II.
- If the mainstream technology sub-system needs to be strengthened, there is no resource to be used, moreover, the existing resources cannot bring great improvement to technical subsystem and the product's technology reaches its limit, in this situation, the result of technology innovation is the change from the end of one S-curve to the head of another. Now we define this kind of IFR as IFR_RI.
- Low-end customers exist, the product's mainstream performance has over satisfied these customers, but these customers believe the price of this product is too high, the IFR in this situation is defined as IFR_LDI.
- New customers are not satisfied with the performance of one certain auxiliary function's technical subsystem (include constraint system), the IFR they expect is IFR_NDI.

After the classification of user groups' IFR (IFR_II,IFR_RI,IFR_LDI and IFR_NDI) is determined, the authors forecast potential technology according to the following process:

Technology forecasting based on IFR_II: because this is a process of incremental innovation, so we only need to ascertain the mainstream function, and define product's IFR according to the mainstream function, then choose the technology which is more advanced and close to IFR to replace the existing technology(See Fig.4).

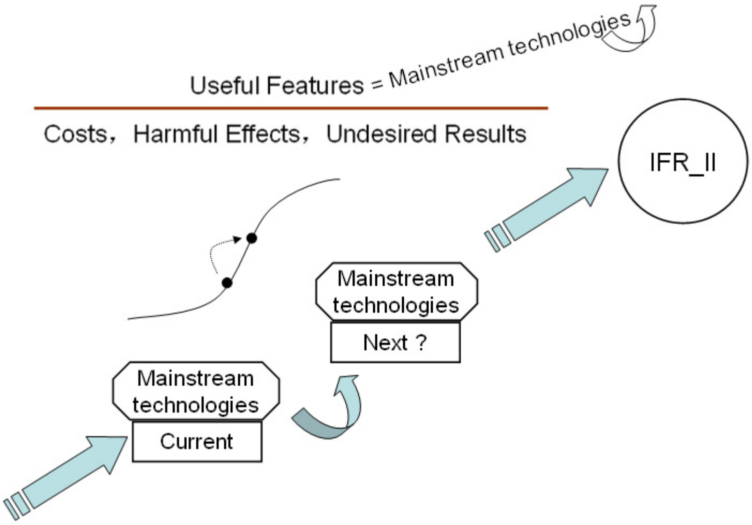

Fig.4. Technology forecasting model based on IFR_II

Technology forecasting based on IFR_RI：IFR_RI is also the innovative improvement of mainstream technology, but it needs major improvement, because the current technology principles can not meet the requirements, so it is necessary to draw support from resources outside the industry, or there is one possibility, technology obtains breakthrough, and then becomes an absolute new technology (See Fig.5).

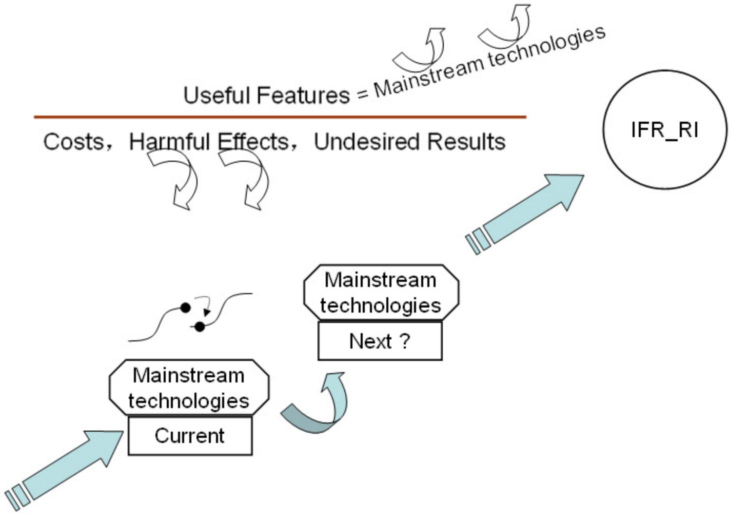

Fig.5. Technology forecasting model based on IFR_RI

Technology forecasting based on IFR_LDI: Low-end customers exist, the IFR they expect behaves as the reduction of cost, and usually the mainstream function of the product evolves excessively for these customers, so IFR_LDI can be realized by reducing the mainstream function and cost (See Fig.6).

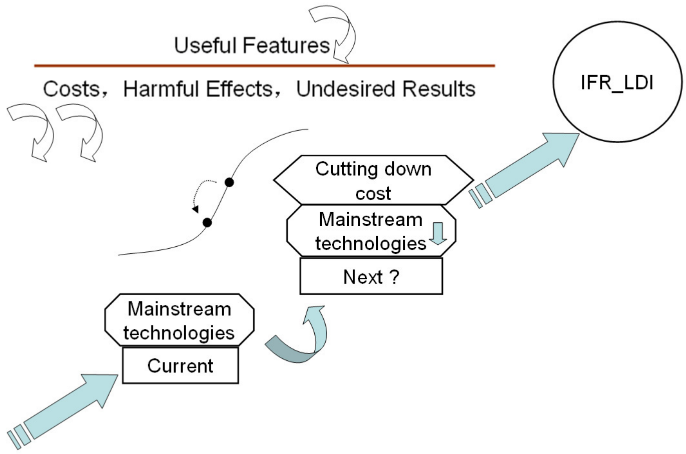

Fig.6. Technology forecasting model based on IFR_LDI

Technology forecasting based on IFR_NDI: New customers exist, the IFR they expect behaves as the improvement of auxiliary function's performance, and the mainstream function is over satisfied for customers, so in order to balance the problem of cost increase caused by strengthening the auxiliary function, we can take a measure of reducing mainstream function to cut cost (See Fig.7).

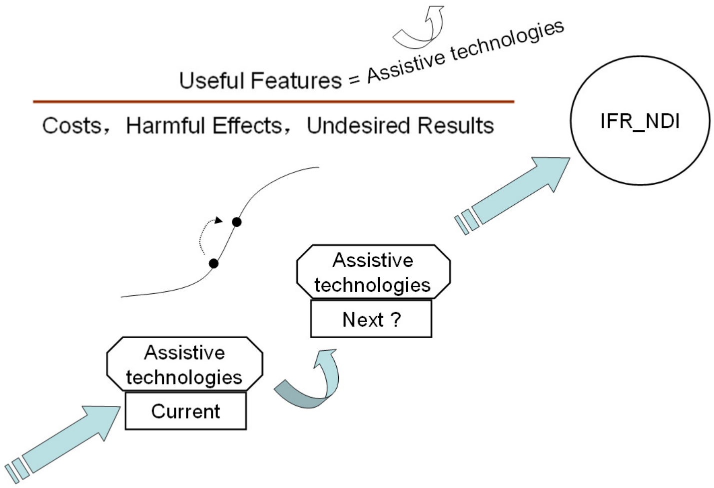

Fig.7. Technology forecasting model based on IFR_NDI

4. Case Study: technology evolution bifurcation of desk lamp

As Seen from Fig.8, it is the technological forecasting verification process of evolution bifurcations, in order to illustrate the problem, the verification result of this case is postmortem analysis process.

Step1: Survey of customer needs. There are 8 items of customer requirements collected by survey.

Step2: Description of IFR. Facing customer needs, they are bulb, pedestal, column, lampshade, price, economy energy, operability, portability respectively, as is shown in Fig. 8, correspondingly, there are 8 descriptions of IFR.

Step3: Decomposition of product's technology system. Engineers define technology sub-system, distinguish mainstream technologies (bulb, lampshade) from auxiliary technologies (others).

Step4: According to the decomposition result of technical system, by comparison of the current state of product's technology sub-system and the IFR of each user group, we got the classification of IFR and 8 kinds of new products.

For the IFR of brightness, the new product is eye protection table lamp. It increases the frequency of light flashing and reduces the glare effect, in addition, the light of eye protection table lamp is soft, so eye protection table lamp helps customer alleviate eye fatigue and makes them feel comfortable, it is popular.

For the IFR of stability, there is a lamp with magnetic base. The base of the lamp is equipped with a magnet, so wherever you want to place the lamp, you can realize your wish.

For the IFR of support, the lamp has flexible pole, it can bend or turn around just as your wish. This kind of desk lamp has a flexible supporting system.

For the IFR of regulation, because there is dust in the environment, the desk lamp with lampshade is popular. It can make the lamp stay away from dust and keep clean, so it is recognized by many customers.

For the IFR of low cost, the lamp with plastic shell is a priority selection for low-end customers. In order to reduce cost, engineers choose plastic instead of other traditional materials, the plastic lamp greatly reduces the cost of lamps.

For the IFR of low energy, solar energy lamp saves energy and is friendly to environment. The working principle of solar energy lamp is that the solar panels absorb solar energy through light first, and converts light energy to electric energy, then stores them in the battery. When customers need lighting, they just need to open the switch and enjoy lighting.

For the IFR of convenience, dimming lights through touching bring great convenience to customers. When you want to adjust the brightness of the light, you only need to touch the induction position gently, it helps customers save both time and labour, so it is convenient.

For the IFR of portability, the folding desk lamp is portable. If you want to carry one lamp, then the folding lamp is your choice, it can save space for you. When you do not use it, you just need to fold it and place it in your bag, it is so portable.

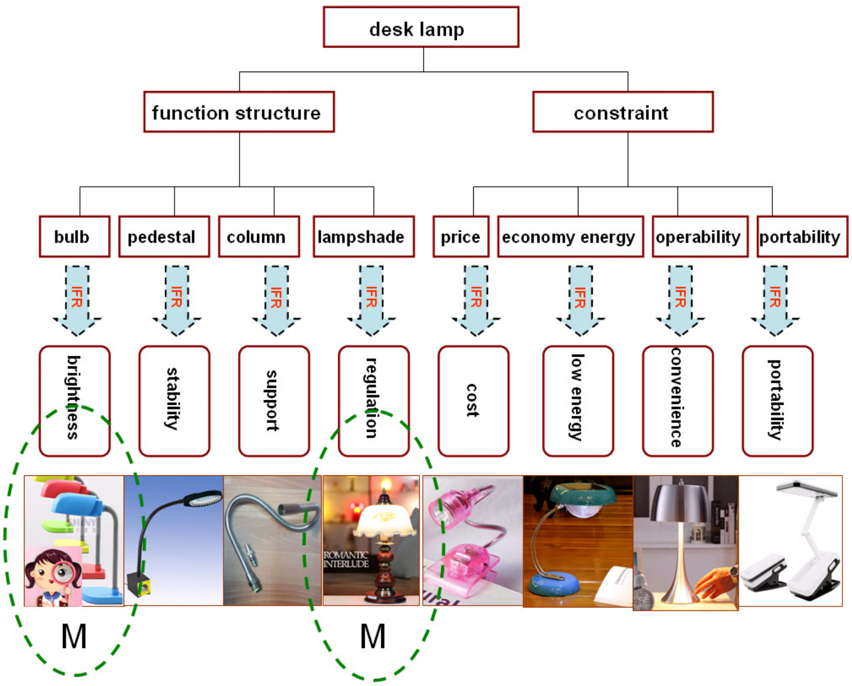

Fig.8. Technology forecasting process of desk lamp

5. Conclusions

To increase the ideality of products is always pursed by enterprises, so the research on how to realize ideal result is critical for engineers. However, with the evolution of customer needs, product's ideal result may generate various bifurcation points. In view of differences of technology evolution bifurcation, the paper divides IFR into four classifications, i.e. IFR_II, IFR_RI, IFR_LDI and IFR_NDI, besides, because one system is made up of several sub-systems, the problem of realizing IFR of the whole technology system is transformed to the problem of realizing IFR of one or some sub-systems. The paper proposes a forecasting process of technology evolution bifurcations based on four classifications of IFRs and gives the forecasting process of potential technologies.

At the end of this paper, the authors take desk lamp for example and conduct detailed postmortem analysis to verify the effectiveness of this technology prediction process. We can see from this case study that realizing IFR of one or some sub-systems is critical to the product's innovation, so it shows that the research on IFR of technological evolution bifurcations is important and effective.

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