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A STUDY ON MULTI-FIELDS OPTIMAL ALLOCATION MODEL OF FUNDS BASED ON BASIC PROSPECTIVE RESEARCH UNDER SHORTAGE OF FUNDS

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Abstract: The State Grid Corporation (SGC) faced with many problems in the allocation of funds when carrying out the basic prospective study, such as multi-fields involved, differences between various fields existed, and the capital investment limited. To solve these problems, this paper first established an index system to distinguish the differences and assesses the importance of the technology. Then considering the stages of the basic prospective study and the characteristics of the project types, this paper built a multi-fields optimal allocation model of funds under the shortage of funds. Finally, an example is delivered to illustrate the feasibility of the model using the restrained differential evolution algorithm by MATLAB programming. It provides a way for decision-makers in multi-fields funds allocation.

Keywords: Basic prospective study; the State Grid Corporation; Multi-fields; Optimal allocation of funds; Differential evolution algorithm.

1. Introduction

Basic prospective study belongs to the basic research, which has great strategic significance to the research and frontier exploration of the basic field of the industry. Once successful, it will promote the development of the company greatly and bring considerable economic benefits. Besides, it also makes a strong leading role. In terms of power enterprises, the status qua has a significant effect on the demand for electricity, such as the reducing in macroeconomic growth rate, the industrial transformation, and so on. At the same time, new technologies and new fields are emerging, and plenty of technologies in various fields continue to break through, which also brings a lot of pressure on the power enterprises. They provide both challenges and opportunities for development of the power industry. In short, it has put forward higher

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requirements on the power industry, which requires power enterprises to grasp the cutting edge technology actively in order to adapt to new developments.

At this stage, there are a number of emerging technologies which will have a strategic impact on power enterprises in future, such as energy Internet, smart grid technology, electric vehicles, superconducting cables, mass storage, new energy, big data, cloud computing and so on. In the enterprise perspective, the input of research funds is limited, so it’s essential to ensure coordinated and orderly progress in all fields. Taking the basic prospective study of the State Grid Corporation (SGC) as an example, it is urgent to be solved that the enterprise has to coordination allocation of funds in different technological fields, especially under the shortage of funds, guarantee the development of company’s important technological fields, make the company's development will maximize and meet the objective needs of scientific research.

At present, SGC determines the investment amounts of its subordinates with subjective allocation scheme mostly, and makes planning approval with reference to the investment amount of earlier years (Cui, 2013). At the same time, the index system is single and outdated, although there is a precise representation, it’s not a comprehensive reflection of the actual demand of funds, and its subjectivity is far greater than the objectivity. This will be directly or indirectly affect the scientific research process. Therefore, a set of mature and normative systems is needed, and the funds should be allocated rationally and optimized. In particular, some prospective, critical basic research projects are in more urgent need of a set of special funds allocation method to optimize capital investment in various technological fields, as well as various stages, because of its features such as large investment, long cycle and blurred investment income.

A rational allocation depends on an effective evaluation system. From the perspective of the domestic and international evaluation system of basic prospective research, there are relatively perfect evaluation systems abroad, for example, the framework of research quality evaluation of higher education institutions in UK (REF) (Smith, 2011; Architecture, 2012), its three aspects of evaluation system are to study the quality of output, external influence and the quality of the research environment. We can see it was built on the research results as the main evaluation basis. The United States normalized and systematized technology assessment through “Government Performance and Result Act” (GPRA). The output, input, publications and other aspects of eleven are detailed, and evaluation is more comprehensive, which is mainly for the quantification of project performance and publicity of the project results. France evaluates scientific research through the resource indicators, strategic indicators and competitiveness indicators, and evaluates the level of scientific research with input, output, relationships, benefit and other indicators. Domestic evaluation research started later. Most of the literatures (Moynihan, 2016) build the index system to assess strategic basic research from the scientific research investment, scientific research performance, scientific research achievements and performance influence four aspects, as the basis for the evaluation of basic prospective study. On this basis, the literature (Sun, 2016) also made the expansion of the index system from the perspective of talent. In addition, the literature (Zhao, 2014)put forward that the existing basic research evaluation is lack of a theoretical model, and the evaluation does not construct indicators according to the characteristics of the project, and is lack of assessment of social impact value. In general, the existing evaluation system focuses more on the input and output benefits, and is usually after-study evaluations of research in one field. We can see it’s used to examine the performance of the study, rather than conducting pre-study predictive evaluation. In addition, the evaluation system did not evaluate multi-fields at the same time to distinguish the differences and the cross-cutting impact on the company's development, and as a basis for the allocation of funds, it doesn’t tell us how to coordinate the distribution of multi-fields research when the funds is insufficient.

Considering the actual situation of power enterprises, and taking into account the allocation of funds in multiple technological fields, the input of funds is required to take into account the characteristics of technological fields and the division in time dimension, which can reflect the differences between different technological fields and reflect stage characteristics. In this paper, we establish an index system of technology assessment according to the characteristics of basic prospective research. And then establish a corresponding distribution model among different technological fields. Finally the differential evolution algorithm is utilized to solve the problem and the feasibility and validity of the model are illustrated by an example.

2. Technological field evaluation system

2.1 Indicator system constructions

Despite the fact that SGC is only related to power, there are lots of technology fields involved, any field may have a disruptive impact on the development of the industry. Now we choose several most representative technological fields as the analysis objects to construct the model. Conducting expert investigation analysis according to a number of basic prospective research in several fields. The research was carried out in seven technological fields: energy Internet, smart grid, electric vehicles, large-scale energy storage, new energy, superconducting cables, big data and cloud computing. While each technological field is not necessarily independent in time or in space, a breakthrough in one field can impact other fields. For instance, the development and utilization of new energy, large-scale use of electric vehicles will have a huge impact on the energy distribution of the energy Internet and so on. In this paper, for the sake of simplifying the model, we will put the influence into the importance of the technological field for the time being.

Based on the existing basic research projects and the index system of the project portfolio (Lei, 2010; Liu, 2008; Tang, 2012; Li, 2014), this paper combines and reorganizes the indicators according to the characteristics of the power enterprises, and forms the evaluation index system which is aimed to assess the importance of the technological field and the company's development willingness. Technological field evaluation mainly assesses the importance to the company from four aspects: the rationality index, adaptability index, development index and technological risk. Indicator construction system as shown in Table 1:

Table 1. Technological field evaluation index system

Indicator name			Interpretation
Evaluation indicator system in technological field	Rationality (A1)	Reasonable degree of project setting（B1）	The setting of the projects should be reasonable according to the development of technology.
		Reasonable degree of project budget（B2）	The funds' investment should be reasonable.
	Adaptability(A2)	National strategic	The research should be in

	integration（B3）	accordance with the objectives of national science and technology strategy, and meet the major needs of the country.
	Adaption degree of development direction（B4）	The field should adapt to the company's development direction.
Expansibility (A3)	Present situation of field research（B5）	The current level and results of basic research in the field.
	Prospect of research application（B6）	Market prospects, promotion, and feasibility.
	Cross impact indicator（B7）	The influence of one technological field affects others within the scope of the assessment.
Technological risk (A4)	Technological advancement（B8）	Make sure the technology can maintain the advanced in the foreseeable future.
	Technological monopoly（B9）	Science develops rapidly, and timeliness is shorter and shorter, the risk of enterprises will increase once the monopoly of technology is lost.
	Technological attractiveness（B10）	The greater the attractiveness of technology is, the smaller the technological risk will be.

2.2 Index weight calculations

Indicators in this paper are mainly for studying the importance of different technological fields when carrying out basic prospective study. Therefore, simple sequence relations method (Chen, 2011) is used to determine weight, and the scores were rated by multiple experts. Then get A layer, B layer of independent weight, respectively, as showed in table 2, 3:

Table 2. Independent weight of A layer

A1	**A2**	**A3**	**A4**
0.27	0.17	0.43	0.14

Table 3. Independent weight of A layer

B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
0.58	0.42	0.38	0.62	0.18	0.53	0.29	0.51	0.20	0.28

So the index comprehensive weights of sub-layer are shown in table 4:

Table 4. Comprehensive weight of sub-layer

B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
0.16	0.11	0.07	0.10	0.08	0.23	0.13	0.07	0.03	0.04

The importance of technological field S within the scope of comparison is given by the summation formula (1):

$$S = \sum_{i=1}^{10} B_i x_i \tag{1}$$

2.3 Importance degree calculations in technological fields

Based on the above indicator system, the seven technological fields were scored by 20 experts. Standardize and normalize the results, then we can get the degree of importance of the seven technological fields within the scope of the comparison. Given the degree of importance of the seven technological fields as shown in Table 5, it can be seen from the results, smart grid, energy Internet, electric vehicles and new energy account for a large proportion in comparison, and it is in line with current expectations and current heat of the study.

Table 5. Degree of importance in seven technological fields

Energy Internet	Smart grid	Electric vehicles	Large-scale energy storage	New energy	Superconducting cables	Big data
0.17	0.19	0.17	0.11	0.15	0.11	0.10

3. Multi-fields funds allocation model and solution

3.1 Multi-fields funds allocation model

SGC, for example, the total capital budget Iin each field is certain, under the condition of the actual capital input ration$u$, funds are allocated in each technological field. No matter which kind of technology it is, the research process is roughly similar. It can be roughly divided into start-up phase (mainly for the formulation of the research framework and investigation), the breakthrough stage (key technological breakthroughs and preliminary applications), and comprehensive application of phase (transformation and application of the achievements). Each stage is a $T = 5$ years planning. According to the characteristics of the stage, the research projects can be divided into basic research projects, key technological breakthrough projects and achievements application projects. Distinct types of projects have different emphases at different stages. These seven technological fields mentioned above are abbreviated as A, B, C, D, E, F, G.As the three phases are similar in modeling, to simplify the model, this paper takes the first stage (starting phase) as an example. This stage concentrates on basic research, so in the allocation of funds, basic research projects should be considered firstly, then key technological breakthroughs, and thirdly achievements application.

The constraints in the allocation of funds are expressed in terms of a quantified formula:

(1) The total budget does not exceed the cost of constraints:

$$\sum_{i=1}^{3}\sum_{j=1}^{T}\left(a_{ij} + \mathrm{b}_{ij} + \mathrm{c}_{ij} + d_{ij} + \mathrm{e}_{ij} + f_{ij} + \mathrm{g}_{ij}\right) \leq uI \tag{2}$$

I represents the company's total budget for the start-up phase; u represents the actual capital investment rate; $i = 1,2,3$represents three types of projects, namely, basic research projects, key technology breakthrough projects and the achievements application projects;a_{ij}represents the actual investment cost of the i-th project in technological field A in the j-th year. Similarly for b_{ij}, c_{ij}, d_{ij},, e_{ij}, f_{ij}, g_{ij} ; Formula (2) shows that all types of projects in all technological fields in the T-year plan, the actual allocation of funds cannot exceed the total amount of actual investmentuI.

(2) Focus on the basic theory research in start-up phase in the technological field:

$$\frac{x_{1j}}{X_{1j}} \geq K,\ \ \mathrm{x} \in \{a,b,c,d,e,f,g\},\ \ X \in \{A,B,C,D,E,F,G\} \tag{3}$$

x_{1j}represents allocation of funds of basic theory projects in a technological field in the j-th year, X_{1j} represents the predicted value, that is, the funds allocation ceiling,$x_{1j} \leq X_{1j}$. The ratio of the budgetary funds to the actual fundsa_{ij}/A_{ij} shall be used as fund guarantee degree in the project i in the j-th year (Zhang, 2015). K is the focused projects' fund guarantee degree. In order to guarantee the basic research project, the formula (3) should be satisfied.

(3) Sort the fund guarantee degrees in start-up phase between three types to highlight the focused stage:

$$\frac{x_{1j}}{X_{1j}} \geq \frac{x_{2j}}{X_{2j}} \geq \frac{x_{3j}}{X_{3j}} \geq \mathrm{M}$$
$$\mathrm{x} \in \{a,b,c,d,e,f,g\}, \quad X \in \{A,B,C,D,E,F,G\} \tag{4}$$

M is the basic fund guarantee degree of other project types; sorts the fund guarantee degree in various technological fields in the j-th year. Reflected in the focus of funds investment in the start-up phase, basic research projects ≥ key technological breakthrough projects ≥ achievements application projects, but all projects should meet the basic fund guarantee degree, that should be greater than M.

(4) Variable constraints:

$$0 < x_{ij} \leq X_{ij}, \quad \mathrm{x} \in \{a,b,c,d,e,f,g\}, \quad X \in \{A,B,C,D,E,F,G\} \tag{5}$$

It is stated that the actual input in the j-th year of each type of project shall not exceed the budgeted input.

(5) Objective function setting:

$$Z = Max\left(\sum_{\substack{\mathrm{x}\in U_x \\ X\in U_X}} Q_X \times \sum_{i=1}^{3}\sum_{j=1}^{T}\frac{x_{ij}}{X_{ij}} \times w_i\right)$$
$$\mathrm{x} \in U_x\{a,b,c,d,e,f,g\}, \quad X \in U_X\{A,B,C,D,E,F,G\} \tag{6}$$

$\mathrm{w}_1, \mathrm{w}_2, \mathrm{w}_3$ are the importance of the three project types respectively, and their values depend on different stages. $Q_A, Q_B, Q_C, Q_D, Q_E, Q_F, Q_G$ are the evaluation weights of the seven technological fields, from Section 2.3. The objective function is set to maximize the annual fund guarantee degree of all kinds of projects and add the weight w_i of the various projects in the start-up phase. At the same time, it can distinguish the importance between varies technological field by weighting importance of technological fields.

Therefore, the objective function of the model is the weighted sum of the fund guarantee degree, which reflects the focus on investment of each technology field and various types of projects in the case that the total investment is specified. Therefore, it can be a good measure of the input of funds in various technological fields.

3.2 Solution based on constrained differential evolution

Differential evolution algorithm is one of numerous intelligent evolutionary algorithms based on population evolution. The algorithm is built on the cooperation and competition of population to solve the optimization problem. Its essence is a greedy genetic algorithm based on the idea of retaining the best. In order to address the optimization problem with constraints, there are two kinds of ideas: One is the penalty function method, and imposes punishment on the objective function to construct the adaptive function. The second is tantamount to transforming into a multi-objective programming problem, using multi-objective technology to deal with. In this paper, an improved method proposed in article (Long, 2012)is used to construct an adaptive function by combining constraint and objective function:

$$f(x) = fit(x) + voi(x) \tag{7}$$

Where, fit(x) is the objective function to find the minimum value; voi(x) expression is:

$$\mathrm{voi}(x) = \sum_{i=1}^{m} max\big(0, g_i(x)\big) \tag{8}$$

$g_i(x)$ is the i-th constraint. Here, the equality constraint $g_i(x) = 0$ is transformed into two inequalities $g_i(x) - \delta \leq 0$ and $g_i(x) + \delta \leq 0$, and δ is a positive number theoretically infinitely small. $fit(x)$ is the objective function value of the individual, and $\mathrm{voi}(x)$ is the extent of the constraint of the problem, which indicates the degree of violation of the individual and the constraint boundary. When $\mathrm{voi}(x) = 0$, the individual is a feasible individual, when $\mathrm{voi}(x) > 0$, is not feasible individuals.

4. Example study

Based on the weight and the model of fund allocation of the above-mentioned technological

fields, seven popular fields of SGC based on basic prospective study are taken as an example.
Assumption 1: Parameter setting: start-up phase planning time: T = 5 years; actual capital investment rate: u = 90%;
Assumption 2: Estimate the total investment budget of the seven fields in the start-up phase of the State Grid at ¥10.723 billion; the budgetary funds in the seven technological fields in the start-up phase are shown in Table 6 (A, B, C, D, E, F, G represent energy internet, smart grid, electric vehicles, large-scale energy storage, new energy, superconducting cables and big data, respectively):

Table 6. Budget table of the start-up phase (Unit: ¥ 100 million)

Technological field	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Capital budget	16.1	31.5	17.1	10.5	11.1	5.43	15.5

Assumption 3: The initial stage focuses on the project guarantee degree K = 0.95, in the other project type funds basic guarantee degree reaches M = 0.8;
Assumption 4: The importance of three types of projects value are$w_1 = 1, w_2 = 0.6, w_3 = 0.4$.

4.1 Calculation

First calculates the forecast value of annual funds. The historical annual capital budget of the research project is based on experience or the company's state of research funds input. For the sake of objectivity, this article draws on the idea of article (Guo, 2002), and uses the annual investment of similar projects to fit, and finds out the fund-time distribution of each kind of project. The fitting data are shown in Table 7:

Table 7. Fitting date table of three types of project(Unit: ¥million)

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Basic study （Ⅰ）	20	50	88	104	110	112	114	113	114	110
Key technological breakthrough （Ⅱ）	22	80	150	180	96	99	179	180	80	60
achievements Application （Ⅲ）	20	58	50	55	112	185	246	294	183	86

Gaussian function fitting:

$$f(x) = a_1 \times e^{-\frac{(x-b_1)^2}{c_1}} + a_2 \times e^{-\frac{(x-b_2)^2}{c_2}} \tag{9}$$

The fitting results are presented in Figs. 1:

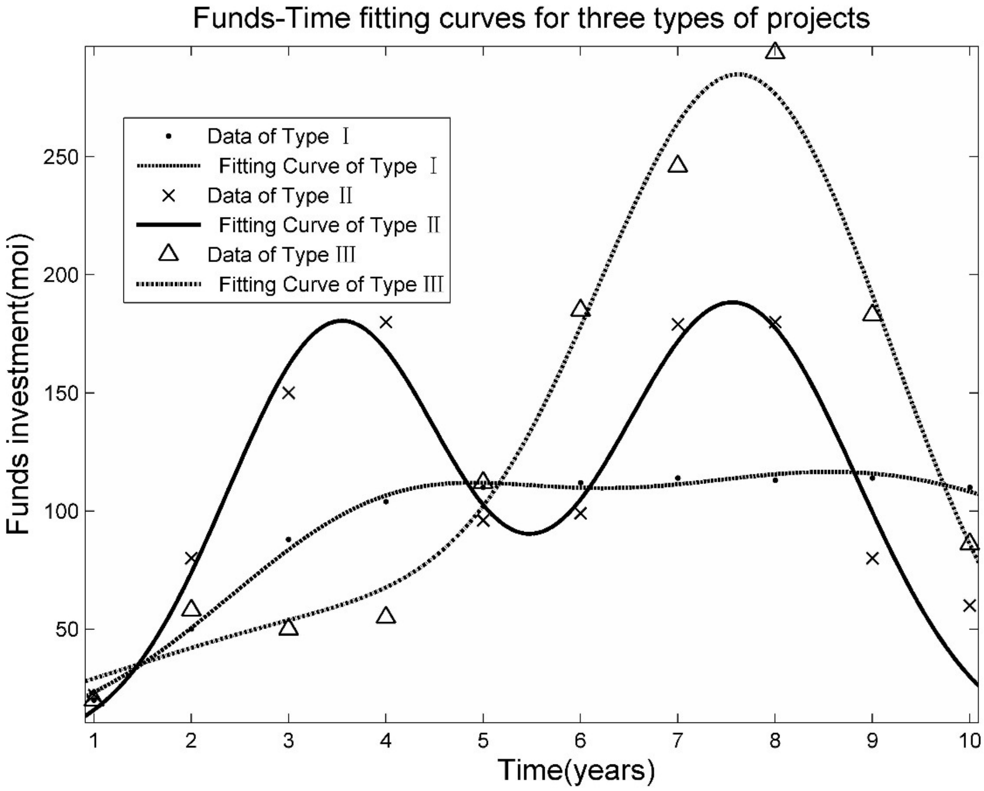

Fig 1. Funds-Time fitting curves for three types of projects

The annual capital investment forecast values obtained from funds-time fitting curve are shown in Table 8:

Table 8. Forecast of capital investment in various technological fields

Project type	Time	Technological field						
		A	B	C	D	E	F	G
Type I	1	6440	13300	3660	1880	2220	1330	2220
	2	11100	23300	6330	3220	3990	2330	3880
	3	11100	23300	6330	3220	3990	2330	3880
	4	11100	23300	6330	3220	3990	2330	3880
	5	7440	15500	4110	2110	2660	1550	2550
Type II	1	13300	36600	14400	21100	17700	2330	22200

	2	14400	37700	15500	22200	17700	2440	23300
	3	22200	59900	24400	34400	27700	3880	36600
	4	6330	17700	6880	9990	7880	1110	10000
	5	50	144	55	80	63	8.8	84
Type III	1	5000	6220	7330	399	2220	1550	4110
	2	9990	12200	14400	766	4330	3000	8000
	3	29900	36600	43300	2330	13300	8880	24400
	4	13300	16600	19900	1000	5990	4000	11100
	5	511	633	755	40	233	155	422

The predicted values are the values of$A_{ij}, B_{ij}, C_{ij}, D_{ij}, E_{ij}, F_{ij}, G_{ij}$, respectively. The variables $a_{ij}, b_{ij}, c_{ij}, d_{ij}, e_{ij}, f_{ij}, g_{ij}$ should satisfy the constraints (2) ~ (5) in 3.3. According to the above assumptions and setting parameters, use MATLAB to conduct iterative calculation, and output the value of decision variables, that is, the amount of funds allocated to each technological field every year.

4.2 Result analyses

In this paper, the constraints are additional to the fitness function, and iterative optimization is separately dealt with feasible solutions and infeasible solutions. And the use of dynamic zoom factor, cannot be only momentary convergence, but also have a better overall. The principal parameters are as follows: the population number$NP = 50$, the maximum scaling factor $F = 0.9$, and the crossover probability $CR = 0.3$. The program runs 10 times, get the optimal objective function value is -9.2875, The optimal solution is shown in Table 9, and the actual total capital investment of 7 technological fields is: $965340 = 1072600 \times 90\% = 965340$ (million), and satisfy the constraints. As the tangible capital investment is 90% of the planned funds, according to the objective function set, it will be fully put into use.

Table 9. Capital allocation from calculation results

Project type	**Time**	**Technological field**

		A	B	C	D	E	F	G
Type I	1	6237.8	13254	3504.4	1871.3	2196.3	1289.6	2148.2
	2	11076	22558	6271.6	3182.9	3938.2	2280	3864.4
	3	10546	22597	6159.4	3080.8	3799	2273.6	3757.6
	4	11019	22503	6081	3136.9	3794.4	2216.9	3863.2
	5	7189.2	14728	3919.8	2016.7	2537.7	1546	2466.8
Type II	1	11012	31816	12918	18951	17075	1954.5	18470
	2	11537	33836	13403	20632	16448	2079.7	22174
	3	19356	49498	23966	30143	25177	3755.2	35409
	4	5980.3	16083	6612.8	9078.8	7414.3	1058.9	8316.6
	5	45.392	129.77	48.267	73.495	59.605	8.7126	80.318
Type III	1	4075	5250.1	6218.3	320.02	2001	1267.2	3360.2
	2	8055.8	10316	11875	645.04	3560.9	2470.7	7546
	3	25885	30173	38706	1988.8	12113	8289.5	20676
	4	12431	13527	16002	852.4	5079.6	3790.5	8961.1
	5	460.36	561.05	625.31	36.252	204.85	153.32	357.32

The fund guarantee degree for each technology field is shown in Figures 2 and 3, and Figure 2 is a diagram of the fund guarantee degree for three projects in a single technological field for five years (for example in the B technology field). In the single technology field, three types of projects present a distinct gradient, and the start-up phase focused on basic research (type I project). As can be seen from Figure 3,there is a similar trend in various technological fields, but there is a slight difference in technological fields in each category. The fund guarantee degree of all projects is above 0.8, and fund guarantee degree for basic research (type I project) in the start-up phase is over 0.95.

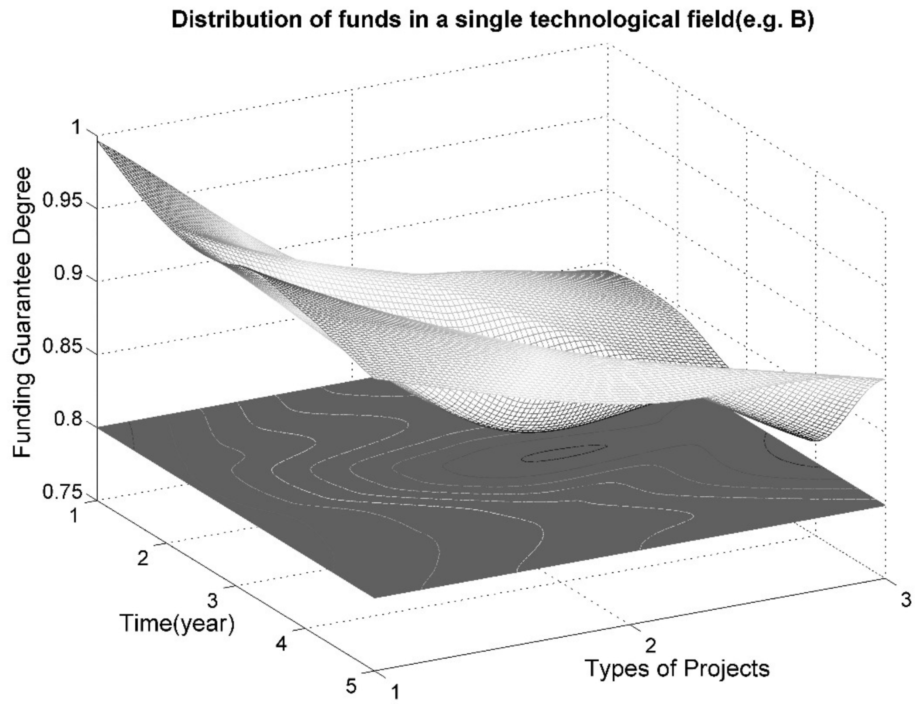

Fig 2. Distribution of funds in a single technological field(e.g. B)

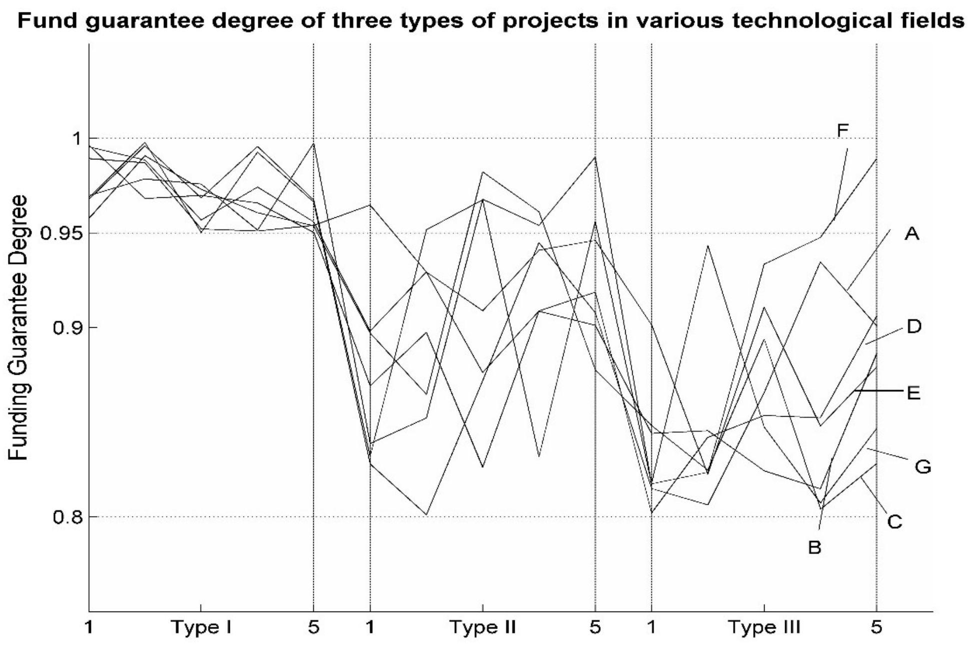

Fig 3. Fund guarantee degree of three types of projects in various technological fields

From the figure, all the decision-making variables of the fund guarantee degree reduce to 0.8 to 0.95 range, the fund guarantee degree of basic projects which are focused on in the start-up phase are all over 0.95.

The example in this paper only considers the allocation of funds in the start-up phase. In the other two phases, only the focus of the project type is different, so only the parameters of w_1, w_2, w_3 need to be modified. In practice, it must be considered that the researches between different fields differ from starting and ending times. Besides there are also many variables in the process of research that make the allocation of funds more complex, so dynamical adjustment should be paid more attention to in deeper study.

5. Conclusions

The allocation of funds belongs to the problem of resource allocation, which is of profound significance to the company. In basic prospective study, because there are plenty of fields develop simultaneously, but also involves the company's major strategic issues, the limited resources should get rational allocation, so that funds allocated to the most objective needs, the most subjective fields, and to maximize the company's research objectives. Based on the actual background, considering the development focus of each field and the development law of technology field, this paper establishes the capital optimal allocation planning model by instructing index system and distinguishing the important degree among various technological fields, combining quantitative and qualitative analysis. And apply the intelligent optimization algorithm to solve it, and get the distribution scheme. The results demonstrate that the proposed algorithm can reasonably plan the multi-stage capital investment in the multi-technology field under the situation that the actual capital investment is insufficient.

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