## RESEARCH ARTICLE

# A Research Funding Allocation Scheme in Multi-Layer Networks for the Growth of Talents

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**ABSTRACT** Talent training is a critical issue of social development. Particularly, talent training in research-oriented universities plays a key role in human resources management. However, achieving effective talent development with minimal macro-regulation becomes a challenging problem that has yet to be solved. As an administrator, the allocation of talent project funding is a viable point of focus, although it is difficult to analyze due to the complex structure of the universities. Inspired by the complex networks, we model the academic talent training problem in universities as a multi-layer network in this paper, and the characteristics which may influence the development of faculty are investigated. Then, the development of each scholar is fitted by a growth curve in the life-course pattern, based on which a research funding allocation scheme is proposed from the perspective of human resources managers. In the proposed scheme, the funding quotas of multiple levels are allocated to different colleges at the proper time to obtain the global optimization of talent training for the whole university. The simulation results show that the proposed funding allocation scheme can improve the final academic ability and the normalized score of outstanding scholars compared with those of the traditional proportion-based allocation scheme.

**INDEX TERMS** Multi-layer networks, academic talents training, life-course pattern, research funding allocation, research-oriented universities.

## I. INTRODUCTION

The cultivation of talents is a crucial issue of the social development [1], [2], which is related to the growth of employees, the development of the enterprise and even the destiny of the country [3]. Especially for the research-oriented university, the growth of faculty is more critical to the progress of national science and technology, as well as the reserve of talent for the country [4], [5]. In the last decades, higher education around the world is in a stage of rapid development both in the number of subjects and students [6], [7], [8]. With the popularization of undergraduate education, graduate education is gradually becoming a popular choice for students who demand to further improve their professionalism [9]. Therefore, academic ability has become a critical criterion for the training of faculty in universities. In addition, it can be

seen from [10] that the productivity of scientific research is closely related to the development of the countries. The countries with more research documents and citations in 2020 also develop rapidly in other aspects, such as economy, military and culture, which is also inseparable from the improvement of academic capabilities of the scholars in university.

In recent years, some researchers have begun to focus on the growth of scholars in universities in terms of their academic productivity and research ability [11], [12]. In their studies, one of the most important factors that influence the scholars is age [13], [14], [15]. On the one hand, academic research activity is a long-term process in which a lot of time and energy should be invested. It is a great challenge, both physically and spiritually. On the other hand, the research activity is also an accumulation process of knowledge and experience. Early accumulation of experience is very important for later development. Therefore, Gyorffy et al. pointed out that the best age for scientific

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research was around 41 [16]. The scholars in this stage not only have enough research experience but also have favorable physical conditions to support long-term energy consumption.

In order to analyze the impact of age on researchers, a life-course pattern was proposed by Fu et al. in [17], in which the faculty with different characteristics such as gender, the research fields and the learning ability, etc. were analyzed according to their life trajectories [18], [19]. In the analysis of life-course patterns, some classical theories were crucial to model the life trajectories of the faculty in universities, including the cumulative advantage, utility-maximizing and obsolescence theory, etc.

The cumulative advantage is a process of social selection in the field of science through which various opportunities for scientific research, rewards for results and allocation of resources tend to accumulate for certain individual scientists or scientific institutions. The cumulative advantage theory shows that the scholars who have more academic productivity in their earlier research stage may make greater achievements in the latter with a higher probability [20]. This is due to that earlier positive outcomes can provide scholars with correct research experience, more academic awards, social networks, research funding and equipment. This theory is similar to the well-known Matthew effect, which implies that famous scientists usually get more prestige compared with those who are not well-known, even if their achievements are similar. In the same way, reputation is usually given to those who are already well-known on a project [21], [22]. Thus, we will pay more attention to the young scholars with more initial productivity at the beginning of the life-course analysis.

In the field of economics, the utility-maximizing theory states that consumers decide to allocate their money to incomes so that the last dollar spent on each product yields the same amount of extra marginal utility. Similarly, in the process of talent growth, the utility-maximizing theory denotes that the scholars will change their tasks by shifting their priority to different types of work including research, teaching, administration, or professional activities. At the different stages of the career, different faculty may choose their priority from a variety of jobs based on the maximal utility they can gain [23].

Finally, the obsolescence theory presents that the research productivity of scholars may decrease with their age when they are old [24]. This is because the natural decline of intelligence is inevitable when scholars are old and they can not catch up with the cutting-edge development of topics within the context of major technological advances. Therefore, the slow growth of research ability in the late stage of the faculty should be considered in the life-course model [25].

In addition, another crucial factor for the growth of scholars in university is the research funding allocation, especially the granting of talent projects [26], [27], [28]. This is because the resource allocation in the university is usually closely related to the rank of the talent projects obtained by faculty. For example, the number of graduate students, the area

of the laboratory, the funding and the laboratory apparatus are typical resources that should be allocated to the faculty according to their talent projects and these resources may make important impacts on their future development [29], [30]. Scholars with higher ranks in talent projects can obtain more research resources and then develop more rapidly than scholars with lower ranks. Moreover, the faculty with high ranks of talent projects can also catch more external resources such as research funding and awards from the other research institutions in society [31], [32], which is beneficial to the development of faculty. However, if most of the scholars are allocated to higher-rank talent projects, the internal resource of the university tends to be distributed equally among all the faculty, which may decrease the growth rate of the distinguished faculty. Therefore, talent project allocation is critical for the managers of research-oriented universities when the life-course academic ability of all the faculty is analyzed.

In recent years, resource allocation problems were studied in various fields. For example, the human resource management strategies for environmental disruptions were summarised by Kim et al.. in [33]. Besides, Wu et al. studied the regional water resources allocation problem and an effective slime mould algorithm was proposed to solve the optimal problem [34]. In [35], the resource allocation optimization problem was formulated by Jain et al.. for the post-disaster emergency relief, and the meta-heuristics were used to obtain the optimal solution. In addition, Mayerle et al.. proposed a teaching resource matching problem, which was meaningful for the public school system [36]. However, at present, the problem of resource allocation in research-oriented universities has not been addressed effectively, which is a meaningful research component for talent development in universities.

Recently, multi-layer networks have received extensive attention from scholars, which provide a novel research method for the study of resource allocation [37], [38], [39]. In a university, the colleges, the research groups and the faculty form a multi-layer network. Besides, research funding allocation based talent projects, research resources, and academic production can be seen as the input and output among the network nodes. In particular, in this paper, the talent project quota is employed to characterize the research funding allocation problem with a multi-layer network model.

The contributions of this paper are summarized as follows:
1) An academic talent training problem for research-oriented universities is modeled from the perspective of multi-layer networks, in which the life-course academic abilities of faculty and the relevant factors are quantified. To the best of the authors' knowledge, this is the first paper that considers the talent development problem in terms of resource allocation and the life-course model.
2) We fit the life-course academic ability of each scholar by the "S" curve with the consideration of some relevant theories including cumulative advantage, utility-maximizing and obsolescence theory. Through quantification, a clear relationship is established

**TABLE 1.** Contrasting our contribution to the reference.

|  | [17] | [36] | [39] | [40] | [41] | Proposed work |
|---|---|---|---|---|---|---|
| Talent development | ✓ | ✓ |  | ✓ | ✓ | ✓ |
| Life-course model | ✓ |  |  |  | ✓ | ✓ |
| Resource allocation |  | ✓ |  |  |  | ✓ |
| Quantitative analysis | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Multi-layer network |  | ✓ | ✓ |  |  | ✓ |

**TABLE 2.** Main notation and relevant mathematical symbols used in the text.

| Parameter | Meaning |
|---|---|
| $S$ | The number of colleges in University |
| $I_s$ | The number of faculty in college $s$ |
| $J_s$ | The number of research groups in college $s$ |
| $N_{sj}$ | The number of faculty of the $j$th group in college $s$ |
| $y(t)$ | The academic ability of the faculty at time $t$ |
| $U_{si}$ | The $i$th scholar in college $s$ |
| $\lambda_{si}$ | Internal resource transformation of $U_{si}$ |
| $p_{si}$ | Internal resource obtained by $U_{si}$ |
| $q_{si}$ | External resource obtained by $U_{si}$ |
| $c_{si}$ | Matching degree between the college and $U_{si}$ |
| $a_{si}$ | Rank of talent project obtained by $U_{si}$ |
| $P_s^{\text{total}}$ | Total resource of college $s$ |
| $\mathbb{E}[x]$ | The expectation of random variable $x$ |

between the input of resources and the output of academic capabilities in the talent growth process.

3) An effective talent project allocation scheme is proposed for the introduced model to maximize the overall growth of all the scholars in different colleges and ensure the development of outstanding scholars at the same time.

4) The simulation results are given and show that the proposed talent project funding allocation scheme can achieve a better average score than the traditional proportional-based allocation scheme.

Our new contributions are boldly and explicitly contrasted to the literature at a glance in Table 1.

The rest of this paper is organized as follows. Section II introduces the system model. The proposed talent project allocation scheme and relevant mechanism are explained in Section III. In addition, the numerical simulations of the proposed scheme are analyzed in Section IV. Finally, we concluded this paper in Section V.

The main notation and relevant mathematical symbols used in the text are summarized in Table 2.

## II. SYSTEM MODEL

As shown in Fig. 1, a research-oriented university with $S$ colleges is considered in this paper. In the $s$th college, there are $I_s$ faculty and they form $J_s$ research groups to achieve better academic research results. It is assumed that the number of faculty in the $j$th group of college $i$ is $N_{ij}$. Each year, the university has several talent project funding to support

the scientific research of outstanding talents in each college. These project funding will first be assigned by the school to the colleges, which will then assign them to the individuals in the groups. Then, from this perspective, the university, the $S$ colleges, the research groups and individuals form a complex multi-layer network. Due to the talent project funding allocation, the flow of resources in college and the growth of talent are coupled with each other, it is difficult to analyze with traditional methods. Therefore the resource allocation analysis approach for the multi-layer networks can be applied to solve this complex problem.

As for each scholar, a life-course ability model is used to analyze the development process of talents in research-oriented universities. According to the statistical results in [40], the age of the elected members of the Chinese Academy of Sciences was concentrated between 51 and 65 years old. In addition, depending on the stage of education in different countries, the average age at which researchers receive their PhD and begin full-time research is between 28 and 30 years old. Hence, in this model, the scientific research ability of researchers is analyzed among the age of 28 to 68 in terms of the degree of discipline matching, the work environment, the talent project quota allocation scheme, and the resources within and outside the college. In the analysis of the life-course ability, several prevailing and relevant theories including cumulative advantage, utility-maximizing and the obsolescence theory are considered. According to these rules and the study in literature [41], we use the "S" curve to fit the development process of the faculty, the function of which is shown in Eq. (1)

$$y(t) = \frac{1}{1 + e^{-t}}. \tag{1}$$

The corresponding ability curve of a researcher is shown in Fig. 2, where $t \in [-3, 9]$ and the sampling rate is $\frac{10}{3}$. It can be seen from the figure that the research ability of academic researchers increases slowly in the early stage of their careers. Then, there will be a dramatic increase between 35 and 45 when they are in the middle stage of their careers. Finally, according to the utility-maximizing and the obsolescence theory, when they are at the age of over 45, both competent and less competent researchers will choose to reduce their research efforts over time, because they think other tasks may be more advantageous. Faculty might spend more time in administrative jobs or professional activities outside the university once they think that further effort in research cannot increase their chances of rewards. Therefore, their ability curves increase slowly again and their ability will be close to the maximum value of their lives.

According to the theories mentioned above, we use the derivative of Eq. (1) to fit the variation of their ability curves in each year for the purpose of analyzing the life-course academic ability of the faculty quantitatively. The derivative of Eq. (1) can be calculated as

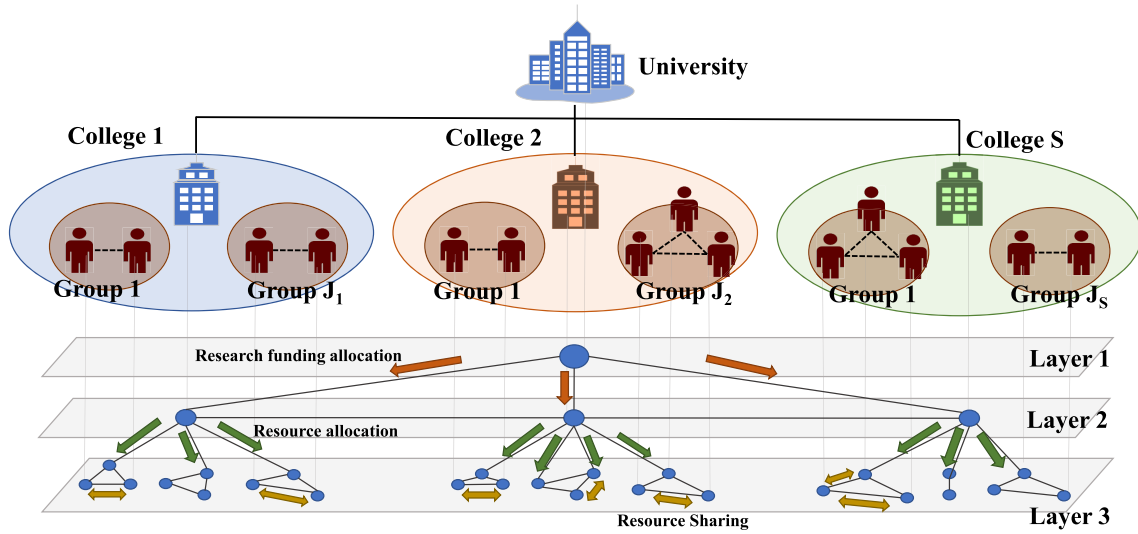$$y'(t) = \frac{e^{-t}}{\left(1 + e^{-t}\right)^2}. \tag{2}$$

FIGURE 1. System model of the proposed research funding allocation scheme and corresponding multi-layer network.
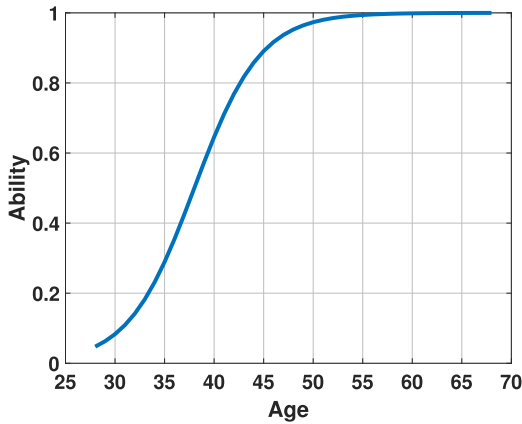


FIGURE 2. Academic ability curve.

Besides, with consideration of the other factors which may affect the scholars, the discrete academic ability increment of $U_{si}$ in their $n$th year can be denoted as

$$\Delta y_{si}[n] = \frac{k_{si}[n]\, e^{-t[n]}}{\left(1 + e^{-t[n]}\right)^2},$$ (3)

where $k_{si}[n]$ can be seen as the growth factor of $U_{si}$, which includes the internal resource $p_{si}[n]$ allocated by the college, the external resource $q_{si}[n]$ attracted by the scholars and the ability of internal resource transformation $\lambda_{si}$. The relationship between these factors can be expressed as

$$k_{si}[n] = \lambda_{si} p_{si}[n] + q_{si}[n].$$ (4)

For internal resource transformation ability $\lambda_{si}$, it can be modeled as a random scalar following the Gaussian distribution, i.e., $\lambda_{si} \sim N\left(c_{si}, \sigma_0^2\right)$, where $c_{si}$ is the matching degree between the college and the majors of the researchers. The variance $\sigma_0^2$ reflects their adaptability to the working environment, which means that if the scholars can not adapt to the working environment, they can not utilize the resource

from the colleges effectively even if their majors coincide with the discipline of the colleges. Therefore, fewer internal resources will be allocated to these people with a higher probability.

As mentioned above, it is assumed that the internal resource allocated to the faculty is proportional to the ranks of obtained talent projects, i.e., $p_{si}[n] \sim N\left(\bar{p}_{si}[n], \sigma_1^2\right)$, where $\bar{p}_{si}[n]$ is the mean of $p_{si}[n]$, which can be calculated by

$$\bar{p}_{si}[n] = \frac{a_{si}[n]}{\sum\limits_{j=1}^{I_s} a_{sj}[n]} P_s^{\text{total}}.$$ (5)

In Eq. (5), $a_{si}[n]$ denotes the indicator which reflects the rank of talent project obtained by $U_{si}$, and $P_s^{\text{total}}$ is the total resource of the $s$th college. It means that the scholars who obtain the higher rank of talent projects may acquire more internal resources with higher probabilities, and the variance $\sigma_1^2$ reflects that the resource allocation in practice is a random event that can not be determined in advance.

At the $n$th year, we assume that the ability of $U_{si}$ to compete for external resources is proportional to his (her) talent protects as well as the current capabilities, and the external resource attracted by $U_{si}$ in the group $G_{sj}$ can be calculated as $a_{si}[n]y_{si}[n-1]$. All the members in the group $G_{sj}$ leave $\frac{1}{\beta}$ of the external resource attracted by themselves and share the rest to the group, which can be equally divided among the members of the group. Then, the mean of total external resource obtained by $U_{si}$ is

$$\bar{q}_{si}[n] = \frac{1}{\beta} a_{si}[n]\, y_{si}[n-1] + \frac{\Sigma_{sj}[n]}{N_{sj}},$$ (6)

where $\Sigma_{sj}[n]$ is the common resource of group $G_{sj}$, which can be calculated by

$$\Sigma_{sj}[n] = \sum_{i \in G_{sj}} \left(1 - \frac{1}{\beta}\right) a_{si}[n]\, y_{si}[n-1].$$ (7)

Similar to the allocation of internal resources, the external resource obtained by $U_{si}$ in practice can be denoted as $q_{si}[n] \sim N(\bar{q}_{si}[n], \sigma_2^2)$. According to Eq. (7), we can find that the outstanding scholars who catch more external resources can drive the development of other people in the same group. It is a crucial basis that should be considered in the project quota allocation problem. Given Eq. (3)-(7), the ability of $U_{si}$ at the $n$th year can be obtained by

$$y_{si}[n] = y_{si}[n-1] + \Delta y_{si}[n]. \tag{8}$$

## III. QUOTA ALLOCATION

According to the theories introduced above, the ranks of talent projects obtained by the faculty are crucial to their development due to both the internal and external resources associated with the ranks. In addition, distinguished scholars with higher ranks of projects can obtain more resources and share their external resources with the team members to accelerate their growth. Therefore, one of the main concerns of project quota allocation is to find outstanding young scholars who have greater development potential and give them higher ranks in talent projects. Then, more internal and external resources will tend to be allocated to this kind of scholar, which can ensure a faster growth rate for distinguished researchers. Finally, due to the existence of groups, the common resource can be shared with people with lower ranks, and they will get more achievements with the help of the team. In this paper, we assume that there are three ranks of talent projects in the career of scholars, which are intermediate, deputy-senior and senior ranks. Denote the indicator value of these three ranks as $r_1$, $r_2$ and $r_3$ respectively, i.e. $a_{si} \in \{r_1, r_2, r_3\}$. In addition, we denote the total quota for the deputy-senior projects as $R_1$ and the total quota for the senior projects as $R_2$, which are limited in a university. Besides, due to the ratio of different ranks should be kept stable in practice, we need to set a maximum limit for the grant of talent projects each year, which is denoted as $m$.

### A. DIRECT GRANT MECHANISM

According to the cumulative theory, the initial achievement may lead to more research productivity in the later stage of the career. It means that if distinguished scholars can publish more high-level academic papers or be widely recognized by peer experts in their research field when they are at their earlier stage of career, they may have more opportunities to obtain higher achievements such as producing more publications or getting more awards with higher probabilities. This is because that young researchers who are outstanding in their research fields may accumulate more successful experiences, research funding, academic awards, social networks, and necessary equipment. These cumulative advantages will be critical support to the later research in their academic careers. In addition, the utility-maximizing theory and the obsolescence theory denote that the growth of academic capabilities will become slow when scholars are old. This is due to the decrease in research effort over time and the natural

decline in intelligence that come with aging. Hence, for the leaders of human resource management in research-oriented universities, it is necessary to discover outstanding young scholars with great potential and give them enough support at the earlier stage of their careers. Then, they can develop more rapidly and achieve higher levels before their abilities increase slowly in their later career. To this end, we introduce a direct grant mechanism in the proposed scheme. In the following two scenarios, the direct grant mechanism will be implemented for $U_{si}$.

The first scenario is that the faculty whose ability achieves a threshold $Y_1^{th}$ at the beginning of their full-time work in the university can be granted the deputy-senior talent projects. This is the recognition of their initial productions and research capabilities when they begin their academic career. Due to some outstanding scholars beginning to show superior research ability in their master's or doctor's degree, the researchers with more publications and awards at the beginning of their academic career may have greater potential with higher probabilities. Hence, we can support them to directly award the deputy-senior projects. In addition, if the faculty whose ability achieves the threshold $Y_2^{th}$ ($Y_2^{th} > Y_1^{th}$), they can be awarded the senior projects directly. In practice, only a few people can meet this condition, and most distinguished scholars should begin with deputy-senior talent projects. The system model of the first scenario of the direct grant mechanism can be denoted as

$$a_{si}[1] = \begin{cases} r_2, & y_{si}[0] \geq Y_1^{th} \\ r_3, & y_{si}[0] \geq Y_2^{th}. \end{cases} \tag{9}$$

The second scenario is that the faculty whose capabilities achieve the threshold $Y_2^{th}$ before they are 40 years old can be awarded the senior rank of talent projects directly with probability $p_d$. The reason is that a large number of surveys show that most scholars can achieve the largest growth rate of their abilities at the age of 40. Therefore, 40 years old is seen as the upper limit when defining outstanding young scholars in many policies. Hence, scholars who have very distinguished research productions may reach higher achievements in the future with high probabilities. Therefore, they can be granted senior-rank projects to ensure enough preference of the resource and policy from the college, and get more research funding from external. Another reason to support the outstanding young scholars with the direct grant mechanism is that the distinguished scholars can provide more assistance to the other members in the same group if they can develop rapidly, and they indeed tend to achieve better development than others with the existing outstanding achievements. The system model of the second scenario of the direct grant mechanism can be denoted as

$$a_{si}[n] = r_3, \text{ if } y_{si}[n-1] \geq Y_2^{th} \text{ and } 1 < n \leq 12, \tag{10}$$

which occurred with probability $p_d$. It is worth noting that the people who catch the opportunity to be granted higher ranks of talent projects directly do not account for the total quota of the university.

## B. ESTIMATION OF THE INTERNAL RESOURCE TRANSFORMATION ABILITY

As for the faculty who can not achieve the threshold of direct grant but can meet the conditions of awarding the higher rank of projects, they should compete for the limited quotas with other people in the same college. In the proposed scheme, we assume that the grant threshold of the deputy-senior projects is $y_1^{th}$, and the threshold of the senior projects is $y_2^{th}$. It means that if $U_{si}$ has been awarded an intermediate rank of talent project and his/her academic ability satisfies $y_{si}[n] \geq y_1^{th}$, then $U_{si}$ can apply for the deputy-senior project. Similarly, if $U_{si}$ has been awarded a deputy-senior project and his/her ability satisfies $y_{si}[n] \geq y_2^{th}$, then $U_{si}$ can apply for the senior project. However, due to the number of deputy-senior and senior projects is limited, the scholars who meet the application condition may not be awarded successfully. The researchers with more production and better environmental adaptability may catch the opportunities with higher probabilities.

Denote the probability that $U_{si}$ can obtain an opportunity by $Pr_{si}[n]$, which is proportional to his/her ability of internal resource transformation $\lambda_{si}$ and the current academic ability $y_{si}[n-1]$, i.e., $Pr_{si}[n] \propto \lambda_{si}y_{si}[n-1]$. The current academic ability can be obtained according to his/her scientific production. However, due to the exact value of $\lambda_{si}$ is not available in practice, we should estimate this parameter according to their actual performance before the allocation of the projects indicator.

In the beginning, due to the lack of valid data, we use the degree of major matching $c_{si}$ to approximate the estimation of $\lambda_{si}$, i.e., $\bar{\lambda}_{si}[0] = c_{si}$, where $\bar{\lambda}_{si}[n]$ is the estimation of $\lambda_{si}$ at time $n$. As for the time $n \geq 1$, we can estimate $\lambda_{si}$ with the previous data $\{y_{si}[0], y_{si}[1], \cdots, y_{si}[n]\}$. According to Eq. (3), we can have

$$
\begin{aligned}
\Delta y_{si}[n] &= \frac{e^{-t[n]}\left(\lambda_{si}p_{si}[n] + q_{si}[n]\right)}{\left(1 + e^{-t[n]}\right)^2} \\
&= \lambda_{si}\frac{e^{-t[n]}p_{si}[n]}{\left(1 + e^{-t[n]}\right)^2} + \frac{e^{-t[n]}q_{si}[n]}{\left(1 + e^{-t[n]}\right)^2}.
\end{aligned} \quad (11)
$$

Due to the parameters $p_{si}[n]$ and $q_{si}[n]$ are random variables which can not be available in practice, we use the mean of these parameters to realize the estimation of $\lambda_{si}$. Summing up all the previous data and taking the expectation of the summation, we can obtain Eq. (12), as shown at the bottom of the next page.

Then, the estimation of $\lambda_{si}$ can be calculated as

$$
\tilde{\lambda}_{si}[n] = \frac{\sum_{x=1}^{n} \Delta y_{si}[x] - \sum_{x=1}^{n} \frac{e^{-t[x]} \cdot \mathbb{E}\{q_{si}[x]\}}{\left(1 + e^{-t[x]}\right)^2}}{\sum_{x=1}^{n} \frac{e^{-t[x]} \cdot \mathbb{E}\{p_{si}[x]\}}{\left(1 + e^{-t[x]}\right)^2}}. \quad (13)
$$

The expectation $\mathbb{E}\{p_{si}[x]\}$ and $\mathbb{E}\{q_{si}[x]\}$ can be obtained from Eq. (5) and Eq. (6) respectively.

## C. PROJECTS QUOTA ALLOCATION

Before determining the optimal project quotas, we should distinguish different kinds of faculty first. At the $n$th year, the number of faculty who obtained the rank of intermediate, deputy-senior and senior projects in college $s$ is denoted as $D_s^L[n]$, $D_s^M[n]$ and $D_s^H[n]$ respectively, which are known before quota allocation. The faculty who obtained the rank of intermediate projects can be further divided into the following four categories: the faculty who satisfy the condition of applying for the deputy-senior project, the faculty who do not satisfy the condition of applying, the faculty who can apply for the senior rank directly, and the faculty who can apply for the deputy-senior projects directly. We can denote the set of faculty in these four categories by $\mathbb{D}_s^{L_1}[n]$, $\mathbb{D}_s^{L_2}[n]$, $\mathbb{D}_s^{L_3}[n]$, $\mathbb{D}_s^{L_4}[n]$, and denote the number of faculty in these four categories by $D_s^{L_1}[n]$, $D_s^{L_2}[n]$, $D_s^{L_3}[n]$, $D_s^{L_4}[n]$ respectively. Similarly, the faculty who obtain the rank of deputy-senior projects can be further divided into the following three categories: the faculty who satisfy the condition of applying for the senior projects, the faculty who do not satisfy the condition of applying, and the faculty who can apply for the senior projects directly. We denote the set of these three categories by $\mathbb{D}_s^{M_1}[n]$, $\mathbb{D}_s^{M_2}[n]$, $\mathbb{D}_s^{M_3}[n]$, and denote the number of faculty in these three categories by $D_s^{M_1}[n]$, $D_s^{M_2}[n]$, $D_s^{M_3}[n]$ respectively. It is not difficult to know that the above-mentioned parameters satisfy the following relationship.

$$
I_s = D_s^L[n] + D_s^M[n] + D_s^H[n]. \quad (14)
$$

$$
D_s^L[n] = D_s^{L_1}[n] + D_s^{L_2}[n] + D_s^{L_3}[n] + D_s^{L_4}[n]. \quad (15)
$$

$$
D_s^M[n] = D_s^{M_1}[n] + D_s^{M_2}[n] + D_s^{M_3}[n]. \quad (16)
$$

Assume that at the $n$th year, the quota of deputy-senior projects allocated to college $s$ is $X_s^D[n]$, and the quota of the senior projects allocated to college $s$ is $X_s^S[n]$. With the estimated $\tilde{\lambda}_{si}$, we can determine the optimal allocation strategy by solving the optimization problem in Eq. (17), as shown at the bottom of the next page, where $\alpha$ in Eq. (17) is a parameter reflecting the preference to the faculty with high academic ability, which satisfies $\alpha \geq 1$. It means that the larger the parameter $\alpha$, the proposed scheme is more inclined to cultivate excellent scholars with high academic ability, even though the growth of some ordinary scholars may be sacrificed at the beginning of their careers because of the limited internal resource. Actually, the intellectual contribution of excellent scholars such as academicians may be several times that of other scholars. Therefore, the parameter $\alpha$ should be set reasonably in the objective function of Eq. (17) to reflect the importance of the distinguished scholars. Then, the proposed scheme can give more priority to ensure the growth of outstanding researchers. In addition, distinguished scholars can also drive the development of other members in the same group by sharing their resources. Hence, giving more weight to the distinguished faculty is usually beneficial to the whole personnel system.

The optimal problem in Eq. (17) is difficult to solve due to the existence of expectations. Therefore, we simplify the

objective function as

$$\mathbb{E}\left\{\sum_{s=1}^{S}\sum_{i=1}^{I_s}(y_{si}[n]+\Delta y_{si}[n+1])^{\alpha}\right\}$$
$$=\sum_{s=1}^{S}\sum_{i=1}^{I_s}\mathbb{E}\left\{(y_{si}[n]+\Delta y_{si}[n+1])^{\alpha}\right\}. \quad (18)$$

Due to $n \geq 0$, $\alpha \geq 1$ and $y_{si}[n]+\Delta y_{si}[n+1] \geq 0$, therefore $(y_{si}[n]+\Delta y_{si}[n+1])^{\alpha}$ is convex. Then, according to the Jensen Inequality, we can obtain

$$\mathbb{E}\left\{(y_{si}[n]+\Delta y_{si}[n+1])^{\alpha}\right\}$$
$$\geq (\mathbb{E}\{y_{si}[n]+\Delta y_{si}[n+1]\})^{\alpha}$$
$$= (y_{si}[n]+\mathbb{E}\{\Delta y_{si}[n+1]\})^{\alpha}. \quad (19)$$

Then, we can scale the original optimization problem (17) to the optimization problem shown in Eq. (20), at the bottom of the next page, and obtain a suboptimal solution of the original problem.

According to Eq. (3) and Eq. (4), we can rewrite the expectation $\mathbb{E}\{\Delta y_{si}[n+1]\}$ in Eq. (20) to the format shown in (21), at the bottom of the next page.

Suppose that at the $n$th year, $X_s^L$ deputy-senior projects and $X_s^H$ senior projects are allocated to college $s$. Then, according to Eq. (14), (15) and (16), the numbers of faculty with different ranks at the $(n + 1)$th year are

$$D_s^L[n+1]=D_s^L[n]-X_s^L-D_s^{L_3}[n]-D_s^{L_4}[n]. \quad (22)$$
$$D_s^M[n+1]=D_s^M[n]-X_s^H-D_s^{M_3}[n]+X_s^L+D_s^{L_4}[n]. \quad (23)$$
$$D_s^H[n+1]=D_s^H[n]+X_s^H+D_s^{L_3}[n]+D_s^{M_3}[n]. \quad (24)$$

As mentioned in the previous parts, the internal resource allocated to the faculty is proportional to their ranks. Therefore, $\mathbb{E}\{p_{si}[n+1]\}$ can be calculated as

$$\mathbb{E}\{p_{si}[n+1]\}=\sum_{x=1}^{3}\frac{r_x P_s^{\text{total}}}{\Phi_s}\Pr(a_{si}[n+1]=r_x), \quad (25)$$

where $\Phi_s = r_1 D_s^L[n+1]+r_2 D_s^M[n+1]+r_3 D_s^H[n+1]$. We take the scholar $U_{si}$ who obtains the rank of the intermediate project as an example to explain the calculation of $\Pr(a_{si}[n+1]=r_x)$, $x \in \{1, 2, 3\}$. At the $n$th year, if scholar $U_{si} \in \mathbb{D}_s^{L_2}[n]$, it is easy to know

$$\Pr(a_{si}[n+1]=r_x)=\begin{cases}1, \text{ if } x=1\\0, \text{ otherwise}\end{cases}. \quad (26)$$

In addition, if scholar $U_{si} \in \mathbb{D}_s^{L_3}[n]$, we can obtain

$$\Pr(a_{si}[n+1]=r_x)=\begin{cases}1, \text{ if } x=3\\0, \text{ otherwise}\end{cases}. \quad (27)$$

Similarly, if scholar $U_{si} \in \mathbb{D}_s^{L_4}[n]$, we can have

$$\Pr(a_{si}[n+1]=r_x)=\begin{cases}1, \text{ if } x=2\\0, \text{ otherwise}\end{cases}. \quad (28)$$

Otherwise, if scholar $U_{si} \in \mathbb{D}_s^{L_1}[n]$ and $X_s^L = 0$, it means that no indicator is allocated to college $s$. The probability $\Pr(a_{si}[n+1]=r_x)$ is the same as Eq. (26). If scholar $U_{si} \in \mathbb{D}_s^{L_1}[n]$ and $X_s^L = 1$, due to the probability that $U_{si}$ can catch a application opportunity is proportional to $\lambda_{si}$ and $y_{si}[n]$, we can calculate the probability as

$$\Pr(a_{si}[n+1]=r_x)=\begin{cases}1-\frac{y_{si}[n]\cdot\tilde{\lambda}_{si}[n]}{\Gamma_s}, \text{ if } x=1\\\frac{y_{si}[n]\cdot\tilde{\lambda}_{si}[n]}{\Gamma_s}, \text{ if } x=2\\0, \text{ otherwise}\end{cases}. \quad (29)$$

where $\Gamma_s = \sum_{d\in\mathbb{D}_s^{L_1}} y_{sd}[n]\cdot\tilde{\lambda}_{sd}[n]$. Finally, if scholar $U_{si} \in \mathbb{D}_s^{L_1}[n]$ and $X_s^L > 1$, we can obtain the probability as shown in Eq. (30), at the bottom of the next page. where $\theta_{si}$ is the grant probability of $U_{si}$ when only one quota is allocated to college $s$, which can be calculated by Eq. (29).

*Proof:* Suppose that the index of faculty in $\mathbb{D}_s^{L_1}$ is $\{d_1, d_2, \cdots, d_{D_s^{L_1}}\}$ and the index of faculty who catch the

$$\mathbb{E}\left\{\sum_{x=1}^{n}\Delta y_{si}[x]\right\}=\sum_{x=1}^{n}\Delta y_{si}[x]$$
$$=\tilde{\lambda}_{si}\sum_{x=1}^{n}\frac{e^{-t[x]}\cdot\mathbb{E}\{p_{si}[x]\}}{\left(1+e^{-t[x]}\right)^2}+\sum_{x=1}^{n}\frac{e^{-t[x]}\cdot\mathbb{E}\{q_{si}[x]\}}{\left(1+e^{-t[x]}\right)^2}. \quad (12)$$

$$\left\{X_1^L[n],\cdots,X_S^L[n],X_1^H[n],\cdots,X_S^H[n]\right\}=\underset{\{X_1^D,\cdots,X_S^D,X_1^S,\cdots,X_S^S\}}{\arg\max}\mathbb{E}\left\{\sum_{s=1}^{S}\sum_{i=1}^{I_s}(y_{si}[n]+\Delta y_{si}[n+1])^{\alpha}\right\}$$
$$s.t. X_s^D \in \mathbb{N}$$
$$X_s^S \in \mathbb{N}$$
$$X_s^D \leq \min\left\{R^D[n], D_s^{L_1}[n], m\right\}$$
$$X_s^S \leq \min\left\{R^S[n], D_s^{M_1}[n], m\right\}, \quad (17)$$

grant opportunity is $\mathbb{X} = \left\{ d_{x_1}, d_{x_2}, \cdots, d_{X_s^L} \right\}$. The probability that $U_{si}$ with $i \in \mathbb{D}_s^{L_1}$ can obtain the opportunity to be granted the talent project can be denoted as

$$\Pr(i \in \mathbb{X}) = \frac{\sum\limits_{\bar{\mathbb{X}} \in \bar{\mathbb{D}}_s^{L_1}} \left( \theta_{si} + \theta_{sd_{x_1}} + \theta_{sd_{x_2}} + \cdots + \theta_{sd_{X_s^L}} \right)}{\sum\limits_{\mathbb{X} \in \mathbb{D}_s^{L_1}} \left( \theta_{sd_{x_1}} + \theta_{sd_{x_2}} + \cdots + \theta_{sd_{X_s^L}} \right)}, \tag{31}$$

where $\bar{\mathbb{X}}$ is the set that remove $i$ from $\mathbb{X}$ and $\bar{\mathbb{D}}_s^{L_1}$ is the set that remove $i$ from $\mathbb{D}_s^{L_1}$. Then, the numerator of Eq. (31) can be rewritten as

$$\sum_{\bar{\mathbb{X}} \in \bar{\mathbb{D}}} \left( \theta_i + \theta_{d_{x_1}} + \theta_{d_{x_2}} + \cdots + \theta_{d_{X_s^L}} \right)$$
$$= C_{D_s^{L_1}-1}^{X_s^L-1} \cdot \theta_{si} + \sum_{\bar{\mathbb{X}} \in \bar{\mathbb{D}}} \left( \theta_{sd_{x_1}} + \theta_{sd_{x_2}} + \cdots + \theta_{sd_{X_s^L}} \right)$$
$$= C_{D_s^{L_1}-1}^{X_s^L-1} \cdot \theta_{si} + C_{D_s^{L_1}-2}^{X_s^L-2} \cdot (1 - \theta_{si}). \tag{32}$$

In addition, the denominator of Eq. (31) can be rewritten as

$$\sum_{\mathbb{X} \in \mathbb{D}} \left( \theta_{d_{x_1}} + \cdots + \theta_{d_{X_s^L}} \right)$$
$$= C_{D_s^{L_1}-1}^{X_s^L-1} \cdot \left( \theta_{d_1} + \theta_{d_2} + \cdots + \theta_{d_{D_s^{L_1}}} \right)$$
$$= C_{D_s^{L_1}-1}^{X_s^L-1}, \tag{33}$$

which completes the proof. ∎

Similarly, if $U_{si}$ is awarded the rank of deputy-senior project and $U_{si} \in \mathbb{D}_s^{M_2}$, or $U_{si} \in \mathbb{D}_s^{M_1}$ but the allocated quota $X_s^H = 0$, we can get the probability $\Pr(a_{si}[n+1] = r_x)$ as

$$\Pr(a_{si}[n+1] = r_x) = \begin{cases} 1, & \text{if } x = 2 \\ 0, & \text{otherwise} \end{cases}. \tag{34}$$

In addition, if $U_{si} \in \mathbb{D}_s^{M_3}$, he or she can catch the project with senior rank directly. Therefore

$$\Pr(a_{si}[n+1] = r_x) = \begin{cases} 1, & \text{if } x = 3 \\ 0, & \text{otherwise} \end{cases}. \tag{35}$$

Otherwise, if $U_{si} \in \mathbb{D}_s^{M_1}$ and $X_s^H = 1$, the probability $\Pr(a_{si}[n+1] = r_x)$ can be calculated as

$$\Pr(a_{si}[n+1] = r_x) = \begin{cases} 1 - \frac{y_{si}[n] \cdot \tilde{\lambda}_{si}[n]}{\Gamma_s}, & \text{if } x = 2 \\ \frac{y_{si}[n] \cdot \tilde{\lambda}_{si}[n]}{\Gamma_s}, & \text{if } x = 3 \\ 0, & \text{otherwise} \end{cases}, \tag{36}$$

where $\Gamma_s = \sum\limits_{d \in \mathbb{D}_s^{M_1}} y_{sd}[n] \cdot \tilde{\lambda}_{sd}[n]$. Last, if $U_{si} \in \mathbb{D}_s^{M_1}$ and $X_s^H > 1$, we can get the probability as it is shown in (37), at the bottom of the next page, where $\gamma_{si}$ is the probability of $U_{si}$ catching the project when only one indicator is allocated to college $s$, which can be calculated by (36).

*Proof:* We omit the detailed proof here since it is similar to the proof of Eq. (30). ∎

As for $\mathbb{E}\{q_{si}[n+1]\}$, it can be calculated by (38), as shown at the bottom of the next page, where $\mathbb{E}\{a_{si}[n+1]\}$

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$$\left\{ X_1^L[n], \cdots, X_S^L[n], X_1^H[n], \cdots, X_S^H[n] \right\} = \underset{\{X_1^D, \cdots, X_S^D, X_1^S, \cdots, X_S^S\}}{\arg\max} \sum_{s=1}^S \sum_{i=1}^{I_s} (y_{si}[n] + \mathbb{E}\{\Delta y_{si}[n+1]\})^\alpha$$

$$s.t. X_s^D \in \mathbb{N}$$
$$X_s^S \in \mathbb{N}$$
$$X_s^D \le \min\left\{ R^D[n], D_s^{L_1}[n], m \right\}$$
$$X_s^S \le \min\left\{ R^S[n], D_s^{M_1}[n], m \right\}, \tag{20}$$

---

$$\mathbb{E}\{\Delta y_{si}[n+1]\} = \frac{e^{-t[n+1]}}{\left(1 + e^{-t[n+1]}\right)^2} \cdot \mathbb{E}\left\{ \tilde{\lambda}_{si} p_{si}[n+1] + q_{si}[n+1] \right\}$$

$$= \frac{e^{-t[n+1]}}{\left(1 + e^{-t[n+1]}\right)^2} \cdot \left( \tilde{\lambda}_{si} \mathbb{E}\{p_{si}[n+1]\} + \mathbb{E}\{q_{si}[n+1]\} \right). \tag{21}$$

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$$\Pr(a_{si}[n+1] = r_x) = \begin{cases} 1 - \dfrac{C_{D_s^{L_1}[n]-1}^{X_s^L-1} \cdot \theta_{si} + C_{D_s^{L_1}[n]-2}^{X_s^L-2} \cdot (1-\theta_{si})}{C_{D_s^{L_1}[n]-1}^{X_s^L-1}}, & \text{if } x = 1 \\ \dfrac{C_{D_s^{L_1}[n]-1}^{X_s^L-1} \cdot \theta_{si} + C_{D_s^{L_1}[n]-2}^{X_s^L-2} \cdot (1-\theta_{si})}{C_{D_s^{L_1}[n]-1}^{X_s^L-1}}, & \text{if } x = 2 \\ 0, & \text{otherwise} \end{cases}, \tag{30}$$

**Algorithm 1** Indicator Allocation Scheme of Talent Project

1: Initialize $y_{si}[0]$, $c_{si}$ and $\lambda_{si}$.
2: At the $n$th year with $n \in \mathbb{N}$, determine the faculty who can obtain the talent projects directly and update their rank indicator $a_{si}$.
3: For the people $U_{si}$ who can not catch the projects directly but meet the requirements of the application, estimate their internal resource transformation ability $\tilde{\lambda}_{si}[n]$ according to Eq. (13).
4: Determine the quota allocation scheme of talent projects according to (20).
5: The people who meet the requirements compete for the opportunity of the application according to their abilities and allocated quota. In addition, the people whose academic ability can not meet the requirements remain at their current rank of project. Then, all the indicators $a_{si}[n + 1]$ are determined.
6: During the $n$th year, the faculty finish their research work and their academic abilities have increased by $\Delta y_{si}[n + 1]$ with the internal resource $p_{si}[n + 1]$ and external resource $q_{si}[n + 1]$. Then, the academic ability of $U_{si}$ becomes $y_{si}[n + 1] = y_{si}[n] + \Delta y_{si}[n + 1]$.
7: Set n=n+1. Repeat step 1 to step 5 until the age of faculty reaches the maximum.

can be calculated by Eq. (25)-(37). Then, the final quota allocation scheme of talent projects can be determined by (20) with the obtained $\tilde{\lambda}_{si}$, $\mathbb{E}\{p_{si}[n + 1]\}$ and $\mathbb{E}\{q_{si}[n + 1]\}$. The complete process of the proposed quota allocation scheme is summarized in Algorithm 1.

Although the resource allocation scheme was studied in various fields, to the best of the authors' knowledge, this is the first paper that considers the talent development problem in terms of resource allocation and life-course model. Before that, most universities allocated limited research funding to the colleges based on the ratio of the number of talents in each college, which is denoted by the proportional scheme in this paper. The proportional scheme only concerns the number of faculty who meet the requirements in different colleges. Therefore, the characteristics of each talent and the macro-regulation of resources are ignored. In contrast, the proposed method takes these issues into account in a complete way. In the simulation, the traditional proportional scheme is presented as a comparison of the introduced method, which illustrates the effectiveness of the proposed method.

## IV. SIMULATION RESULTS

In this section, the simulation results are presented to validate the effectiveness of the proposed quota allocation scheme. In the simulation, a simplified research-oriented institute with three colleges is considered. We assume there are 10, 20 and 40 full-time faculty in the 1st, 2nd and 3th college respectively. In addition, the number of groups in each college is set to 3. The number of researchers in the three groups of these colleges is [3, 3, 4], [6, 6, 8] and [10, 10, 20] respectively. The total internal resources are 20, 40 and 40 to reflect the different scales of college. The initial abilities of the researchers are assumed to obey the Gaussian distribution with a mean of 0.5 and a variance of 0.05. The matching degree between the college and the major of researchers are divided into three levels, which are 0.2, 0.4 and 0.6 with the probabilities of 0.2, 0.6, and 0.2 respectively. The variance of $\lambda$ is set to 0.1 to distinguish faculty with different adaptive capacities to the environment. All the parameters used in the simulation are listed in table 3. In addition, it is worth noting that in order to balance the total number of different ranks of projects among the university, we assume that the summation of quotas allocated to different colleges is less than 5 except for direct promotion.

In the simulation, the traditional proportional scheme is presented as a comparison, i.e., the quota allocated to each college is proportional to the number of faculty who meet the application threshold.

$$\Pr\left(a_{si}[n + 1] = r_x\right) = \begin{cases} 1 - \dfrac{C_{D_s^{M_1}[n]-1}^{X_s^H-1} \cdot \gamma_{si} + C_{D_s^{M_1}[n]-2}^{X_s^H-2} \cdot (1-\gamma_{si})}{C_{D_s^{M_1}[n]-1}^{X_s^H-1}}, & \text{if } x = 2 \\ \dfrac{C_{D_s^{M_1}[n]-1}^{X_s^H-1} \cdot \gamma_{si} + C_{D_s^{M_1}[n]-2}^{X_s^H-2} \cdot (1-\gamma_{si})}{C_{D_s^{M_1}[n]-1}^{X_s^H-1}}, & \text{if } x = 3 \\ 0, & \text{otherwise} \end{cases} \tag{37}$$

$$\mathbb{E}\{q_{si}[n + 1]\} = \mathbb{E}\left\{\frac{1}{\beta}a_{si}[n + 1]y_{si}[n] + \frac{\sum\limits_{x \in G_{sj}}\left(1 - \frac{1}{\beta}\right)a_{sx}[n + 1]y_{sx}[n]}{N_{sj}}\right\} \tag{38}$$

$$= \frac{1}{\beta}\mathbb{E}\{a_{si}[n + 1]\}y_{si}[n] + \frac{\sum\limits_{x \in G_{sj}}\left(1 - \frac{1}{\beta}\right)\mathbb{E}\{a_{sx}[n + 1]\}y_{sx}[n]}{N_{sj}}.$$

**TABLE 3.** Summary of parameters used in simulation.

| Parameter | Value |
| --- | --- |
| $S$ | 3 |
| $J_s$ | 3 |
| $\delta_0$ | 0.1 |
| $\delta_1$ | 0.02 |
| $\delta_2$ | 0.02 |
| $\alpha$ | 2 |
| $\beta$ | 2 |
| $p_d$ | 0.3 |
| $Y_1^{\text{th}}, Y_2^{\text{th}}$ | 0.8, 4 |
| $y_1^{\text{th}}, y_2^{\text{th}}$ | 0.8, 4 |
| $R_1, R_2$ | 20, 10 |
| $r_1, r_2, r_3$ | 0.1, 0.3, 1 |
| $I_1, I_2, I_3$ | 10, 20, 40 |
| $N_{11}, N_{12}, N_{13}$ | 3, 3, 4 |
| $N_{21}, N_{22}, N_{23}$ | 6, 6, 8 |
| $N_{31}, N_{32}, N_{33}$ | 10, 10, 20 |
| $P_1^{\text{total}}, P_2^{\text{total}}, P_3^{\text{total}}$ | 20, 40, 40 |
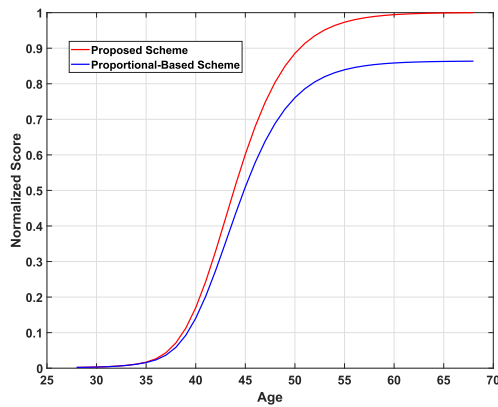


**FIGURE 3.** Average score of the proposed scheme and comparison scheme.

The average score of the proposed scheme and proportional-based scheme are shown in Fig. 3, which is calculated by $\sum_{s=1}^{S} \sum_{i=1}^{I_s} (y_{si}[n])^{\alpha}$. For the convenience of analysis, we normalized the curves by dividing them by their maximum value. In addition, both curves are obtained with the average of 30 random initial data generations, and 30 Monte Carlo iterations in each initial data generation. It can be seen that the proposed scheme can obtain a 13% performance improvement compared with the proportional scheme. It means that the proposed scheme can achieve a better talent training effect in most cases.

In order to clarify the specific impact of the proposed quota allocation scheme, we take out one of the above 30 random experiments and analyze the growth process of all the faculty. Their internal resource transformation ability $\lambda$ and initial
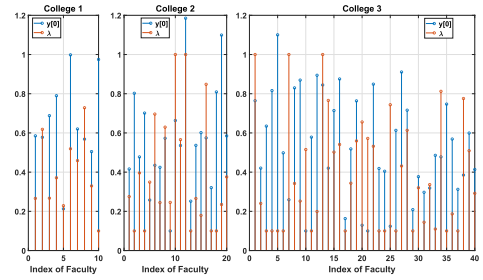


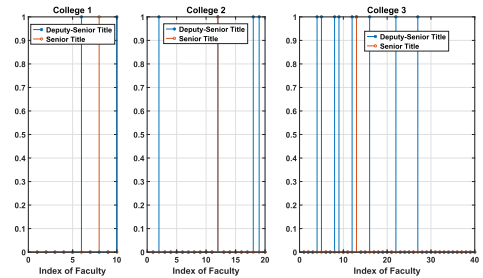**FIGURE 4.** $\lambda$ and $y[0]$ of faculty.



**FIGURE 5.** Direct grant of the proposed scheme.

academic ability $y[0]$ is shown in Fig. 4. It can be seen that the scholars with outstanding initial academic abilities and internal resource transformation abilities are only a small part of the faculty. The proportion of faculty who meet the condition of direct grant for deputy-senior projects is about 20%. In addition, we find that there are some faculty whose initial academic abilities are outstanding while their internal resource transformation abilities are poor. This is because the correlations between their major and college discipline development are low or their environmental adaptability is poor. It is unfavorable for their later growth. On the contrary, some faculty have excellent internal resource transformation abilities while their initial academic abilities are not remarkable. This kind of peolpe can usually develop well if the college provides them with enough resources. The direct grant results of the proposed scheme are shown in Fig. 5. We can find that the faculty whose initial academic abilities are more than $Y_1^{\text{th}}$ can obtain the deputy-senior project when they begin their career, such as the 6th and the 10th scholars in college 1. Moreover, Fig. 5 shows that the 8th scholar in college 1, the 12th scholar in college 2 and the 13th scholar in college 3 are awarded to the projects of senior rank directly in the proposed scheme. According to Fig. 4, these faculty do have higher initial academic abilities and internal resource transformation abilities. Especially for the 8th scholar in college 1, we can find that the higher $\lambda$ is critical for the growth of scholars.

We present the quota allocation results of the deputy-senior rank projects and senior rank projects in Fig. 6 and Fig. 7. It can be seen that the traditional proportional-based scheme allocated the quota according to the number of candidates. On the contrary, the proposed scheme tends to allocate the quota to the college which can obtain more academic ability increase. In addition, we can find that the proposed scheme allocated the quota more slowly than the proportional-based
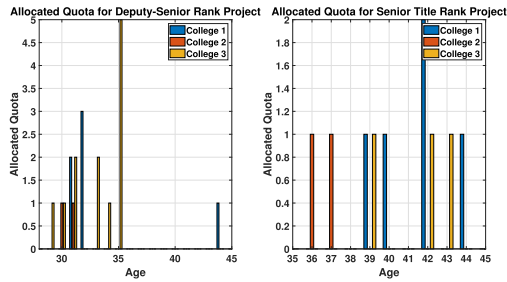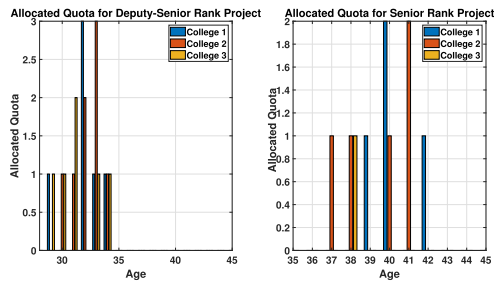
**FIGURE 6.** Allocated indicator of the proposed scheme.



**FIGURE 7.** Allocated indicator of the proportional-based scheme.



**FIGURE 8.** Final rank of the faculty.



**FIGURE 9.** Academic ability of faculty in college 1.



**FIGURE 10.** Academic ability of faculty in college 2.



**FIGURE 11.** Academic ability of faculty in college 3.

scheme. This is because the internal resource of colleges is limited, if more quota is allocated to the college in the early stage, the internal resource allocated to the distinguished people will decrease due to it should be divided among more people with a higher title. Therefore, the proposed scheme allocated the quota more slowly to ensure the growth of a small group of outstanding people. Then, they can drive the development of other members in the same group at a later stage, which is beneficial in the long term.

Then, we present the final rank of talent projects obtained by all the faculty in Fig. 8. It can be seen that the final project ranks of the proposed scheme and the proportional-based scheme are the same due to the excellent scholar can obtain higher rank projects no matter in which scheme. In the proposed scheme, we can find that the number of senior rank projects in college 2 and college 3 is not proportional to the total number of people in the colleges. This is because the average internal resource of college 3 is much less than that of college 2. Then, the scholars in college 3 develop more slowly in the early stage. In addition, it is shown that the scholars who have a larger $\lambda$ such as the 10th person in college 2 and the 7th person in college 3 can obtain the senior rank project even if they do not have a larger initial academic ability, which is consistent with the conclusion proposed before. As for the people with both large initial academic ability and internal resource transformation ability such as the 10th person in college 2, they can catch the higher rank project in the proposed scheme.

In addition, the life growth trajectories of all the faculty are shown in Fig. 9, Fig. 10 and Fig. 11, in which the solid lines and the dashed lines indicate the proposed scheme and the proportional-based scheme respectively. It is not hard to find that the proposed scheme ensures the growth of some outstanding scholars, especially in college 1 and college 2.
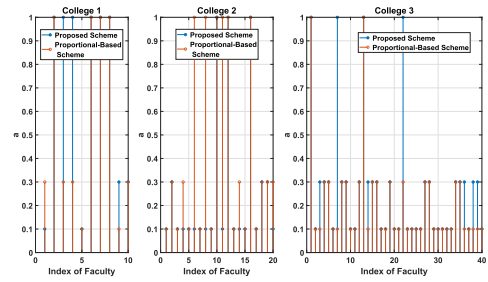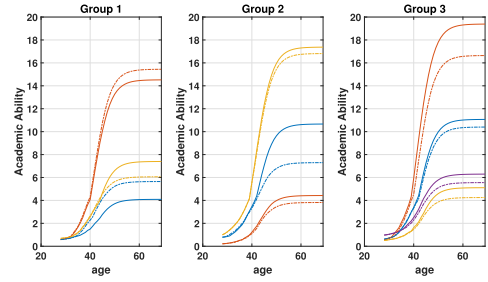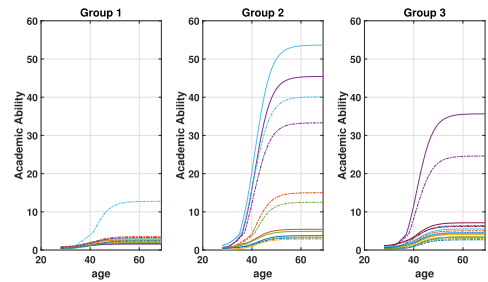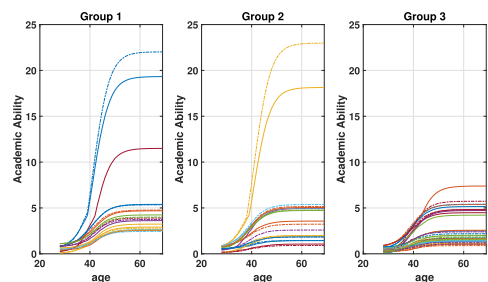
In addition, it can be seen that distinguished scholars can lead the development of other members in the same group. For example, the members in group 3 of college 1 can achieve a higher final ability than group 1 and group 2, even though the initial academic abilities and internal resource transformation abilities of some members in group 3 are less than that of the members in the other two groups. This is because that outstanding scholar can share their external resource with the members of the same group to enhance their development. However, due to the the limited internal resource and its crucial role in the early stage, the scholars with low internal resource transformation abilities can not obtain a high academic ability in the end compared to the outstanding scholars.
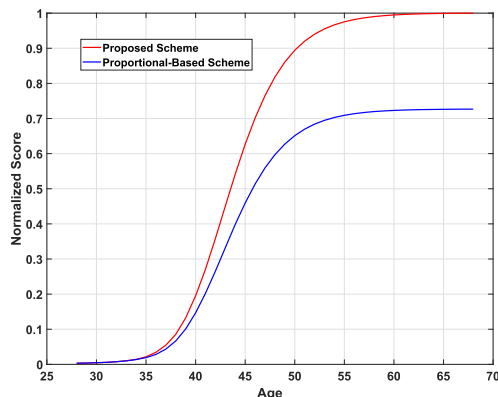
**FIGURE 12.** Normalized score of the selected experiment.

Finally, we show the normalized score of this experiment in Fig. 12. We can see that there are approximately 27% performance improvements in the proposed method compared to the traditional proportional-based scheme. This is because the proposed scheme can ensure the growth of outstanding scholars with more resources at the beginning of their careers and then drive the development of other scholars in the same group with resource sharing. In addition, due to the proposed scheme being more inclined to support the growth of outstanding researchers, the final academic abilities of distinguished scholars in the proposed scheme are far more than that in the proportional-based scheme. Therefore, the proposed scheme can achieve a higher score.

## V. CONCLUSION

In this paper, the talent training process of a research-oriented university is analyzed with the life-course model. Based on this model, a talent project funding allocation scheme is proposed according to multi-layer network theory as a viable point of macro-control, which aims to optimize talent training performance for the whole university. The simulation results show that a sufficient performance improvement can be achieved by the proposed scheme compared to the traditional proportional-based allocation scheme. However, some of the parameters used in this paper are obtained from limited data and practical experience. In future work, more talent development data is needed to fit the parameters of the model proposed in this paper and to further modify the life-course mode model.
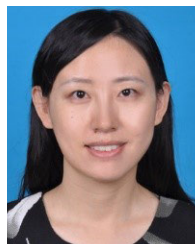
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