Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 55 (2015) 35 – 42

Procedia Computer Science

Information Technology and Quantitative Management (ITQM 2015)

Dynamic programming based research position planning: Empirical analysis from the Chinese Academy of Sciences

Yongjia Xie[a,b], Chang Liu[a,b], Dengsheng Wu[a]*, Yuanping Chen[c], Jiangping Li[a]

[a] *Institute of Policy and Management, Chinese Academy of Sciences, Beijing 100190, China*
[b] *University of Chinese Academy of Sciences, Beijing 100190, China*
[c] *Computer Network Information Center, Chinese Academy of Sciences, Beijing 100190, China*

Abstract

The fast growing number of researchers in China makes the human resources management become a noteworthy issue in scientific research management. However, since the strictly limit to the number and structure of positions in Chinese scientific research management, the Chinese researchers are going to face a brutal promotion stress. This paper puts forward a quantitative method of estimating the research position demand gap as decision support based on the thought of dynamic programming. The personnel data from 2006 to 2014, which is abstracted from the Academia Resource Planning (ARP) system of the Chinese Academy of Sciences (CAS), are applied to the empirical analysis to estimate the human resource demand gap in the 13th Five Year Plan.

Peer-review under responsibility of the Organizing Committee of ITQM 2015

Keywords: scientific research management, position structure, dynamic programming, human resource management, decision support

1. Introduction

With the rapid development of Chinese scientific research's level, the number of high quality papers grew [1]. Despite the comprehensive national strength, the fast growing number of researchers is also one reason that cannot be ignored. Therefore, the human resources management gradually becomes a noteworthy issue in scientific research management. Furthermore, as the backbone of the scientific development, the researcher's position management is an important part of the human resources management.

In the Chinese practice of research management, there are three points that are worth paying attention. Firstly, with the rapid growth of researchers, the human resources management in scientific research management is more complicated [2]. The population is larger and the positions are more diversified, as a result that quantities

* Corresponding author. Tel.: +86-10-59358813.
E-mail address: wds@casipm.ac.cn.

Peer-review under responsibility of the Organizing Committee of ITQM 2015
doi:10.1016/j.procs.2015.07.004

of human resource data are needed to process. Secondly, there is a significant decline in the growth rate of researchers, indicating that the total number of researchers is growing very slowly and may be saturated in the next few years. Thirdly, since the strictly limit to the position management in Chinese scientific research management [3], the Chinese researchers are going to face a brutal promotion stress. In addition to the fast growing tendency in the past several years, this problem is more serious.

For the first question, faced with the large quantities of the human resource data, a decision support system based on the database construction is in need [4]. As for the last two issues, the decision makers need to establish a quantitative model to predict changes in staff positions. This decision support system can help to analyze the promotion rules, adjust position structures and give suggestions on talent introduction [5]. Previous works on related issues please see [6-8].

Aimed at these problems in practice, this paper puts forward a method of estimating the research position demand gap as decision support based on the thought of dynamic programming. In this approach, the dynamic programming method is applied to construct the model to estimate the dynamic change of different titles in research position. In the empirical analysis, the historical personnel data abstracted in the Academia Resource Planning (ARP) system of Chinese Academy of Sciences (CAS) are applied to the proposed model to estimate the demand gap of each title in research position.

2. The proposed method

In this section, the proposed model for estimating the research position demand gap as decision support is illustrated and the steps are given in detail.

The main thought of the proposed method comes from the dynamic programming. Dynamic programming, firstly proposed by Bellman, usually refers to simplifying a decision by breaking it down into a sequence of decision steps over time [9]. It helps the decision makers to know how to realize the desired proportion of every position they have firstly set. The demand gaps of each position, either positive or negative, are given by this model as intermediate results. Therefore, the decision makers can adjust the staff recruitment and dismissal every year in order to reach the target population and proportion. The variables and parameters that are noted in the proposed model are listed in Table 1.

Table 1. The parameters noted in the proposed model

Variables or Parameters	Description
X_{it}	The number of people of i title at t time point
δ_i	The natural retiring rate of i title
γ_i	The separation rate of i title
y	The time one has served at i title
$P_{ij}(y)$	The probability distribution of the i title promoting to j title
$Z_{it}(y)$	The number of people who has already served at i title for y years at t time point

Dynamic personnel changes are caused by three factors, internal promotion, external outflow and external introduction [10]. Firstly, we set the external introduction aside. The external outflow contains the natural retiring rate and separation rate. Therefore, the X_{it} can be deduced by $X_{i(t-1)}$ with natural retiring rate δ_i, separation rate γ_i and the internal promotion. For example, if there are four titles in a research position ($i = 1,2,3,4$) and $i = 1$ represents the highest title yet $i = 4$ represents the lowest title. The iteration formulas can be written as followed in Eq. (1)-(4).Then we take the external introduction into consideration. The human resource demand

gap of every title can be defined as the difference between the expected numbers that the decision maker has preset and the estimated numbers that are calculated with the dynamic programming.

$$X_{1t} = X_{1(t-1)} - \delta_1 X_{1(t-1)} - \gamma_1 X_{1(t-1)} + \sum Z_{2(t-1)}(y) P_{21}(y) \quad (1)$$

$$X_{2t} = X_{2(t-1)} - \delta_2 X_{2(t-1)} - \gamma_2 X_{2(t-1)} - \sum Z_{2(t-1)}(y) P_{21}(y) + \sum Z_{3(t-1)}(y) P_{32}(y) \quad (2)$$

$$X_{3t} = X_{3(t-1)} - \delta_3 X_{3(t-1)} - \gamma_3 X_{3(t-1)} - \sum Z_{3(t-1)}(y) P_{32}(y) + \sum Z_{4(t-1)}(y) P_{43}(y) \quad (3)$$

$$X_{4t} = X_{4(t-1)} - \delta_4 X_{1(t-1)} - \gamma_4 X_{4(t-1)} - \sum Z_{4(t-1)}(y) P_{43}(y) \quad (4)$$

The formulas above include an assumption that the lower title can only be promoted one grade and no Advanced Placement is admitted.

To carry out this model, it can be concluded into 7 steps. Step 1 is the input of the decision making goal. Step 2-6 are the computational process in detail. Step 7 is the iteration process.

Step 1: Set the goal time point, the headcount target (T) and the expected position structure (α_i). It is the goal of the decision makers that they wish to achieve.

Step 2: Add up the number of retirees (R_{it}) by the end of next year. The average of annual retired rate (δ_i) for every title is firstly calculated so that the number of retirees in the next year can be estimated by Eq. (5)

$$R_{it} = \delta_i X_{i(t-1)} \quad (5)$$

Step 3: Estimate the number of the departing personnel (D_{it}) by the end of next year. The average of annual turnover rate (γ_i) for every title is firstly calculated so that the left people in the next year can be estimated by Eq. (6)

$$D_{it} = \gamma_i X_{i(t-1)} \quad (6)$$

Step 4: Estimate the most probable persons who can get promotion (M_{ijt}) in the next year. It is calculated by the people to be promoted multiplying their promotion probability, as shown in Eq. (7)

$$M_{ijt} = \sum Z_{i(t-1)}(y) P_{ij}(y) \quad (7)$$

Step 5: Calculate the most probable number of every title X_{it} by Eq. (1)-(4).

Step 6: Calculate the human resource gap of every title (G_{it}) by Eq. (8).If the gap is positive, its actual meaning is hiring new persons externally. Conversely, if the gap is negative, its actual meaning is that some people have to leave their position.

$$G_{it} = \alpha_i T - X_{it} \quad (8)$$

Step 7: Repeat Step 2-6, calculate the results of every year till the target time point.

3. Empirical study

In this section, the proposed approach is used to estimate the human resource demand gap in the 13th Five Year Plan. The empirical results can help the decision makers to reach the target population and proportion in the next six years.

3.1. Data description

The experimental data we adopted is the personnel data, from 2006 to 2014, abstracted from the Academia Resource Planning (ARP) system of the Chinese Academy of Sciences (CAS).Based on the job nature, the ARP system divides the position into three categories: managerial position, supportive position and research position. In this case study, our experiments mainly focus on the research positions.

Since 2006, the total number of the research positions in CAS has experienced a rapid growth. There are only 19560 research positions in 2006, while it increases to 39293 by then end of 2014 with the annual growth rate of 9.10%.

There are four titles in the research position which are lecturer, senior lecturer, associate professor and professor, respectively. Among the four titles in the research position, the senior lecturer takes the largest proportion and increases the fastest. During 2006-2014, the average annual growth rate of senior lecturer maintained at 12.10%. The associate professor has also increased fast with annual grow rate of 10.05%. The growth rate of these two titles are higher than the growth rate of total research position (9.10%), indicating that the research team of CAS has sufficient growing potential and is in a rapid growth phase. As for the structure of the research team, by 2014, the lecturer, senior lecturer, associate professor and professor positions account for the proportion of 19.82%, 36.02%, 26.44%, 17.28%, respectively.

Table 2. The number of the research positions in CAS (2006-2014)

Titles	2006	2007	2008	2009	2010	2011	2012	2013	2014
Lecturer	4972	5612	6000	7108	7473	7216	7669	7950	7823
Senior lecturer	5768	6686	7888	9153	10708	12383	13343	14204	14215
Associate professor	4869	5218	5711	6384	7182	8150	9274	10182	10434
Professor	3951	4144	4451	4883	5390	5878	6338	6679	6821
Total	19560	21660	24050	27528	30753	33627	36624	39015	39293

3.2. Promotion rules of professional titles

In order to estimate the number of people to be promoted every year, it is essential to find out the promoting rules of every title. Based on the historical data, we add up the promoting time that every person has used. Results show that the promoting rules of different titles are quite different.

Table 3 shows the statistics of the promoting time of each title in research position, from which we begin to see the difference among these titles. The average times of lecturer, senior lecturer and associate professor promoting to senior lecturer, associate professor and professor are 11.19, 6.13 and 4.39 years, respectively. The higher title to be promoted, the longer time is needed. The standard deviations of promoting time are 7.19, 5.50, and 2.62 years, respectively. Most senior researchers used 6 years to get their promotions, most associate researchers used 3 years to get their promotion and most intermediate researchers used 3 years to get their promotion, too. 50% senior researchers used no more than 9 years to get their promotion, while 50% associate researchers and intermediate researchers used 4 years. The kurtosis of promoting time of lecturer is the biggest yet its standard deviation is the smallest, which means when promoted to senior lecturer, the promoting time is more concentrated. Other quantiles of three promoting times are listed in detail in Table 3.

Table 3. The statistics of the promoting time (years)

Titles	Mean	S.D.	Skewness	Kurtosis	Mode	Median
Promoting to senior lecturer	4.39	2.62	3.60	24.94	3	4
Promoting to associate professor	6.13	5.50	2.04	4.12	3	4
Promoting to professor	11.19	7.19	0.54	-0.78	6	9

Through the density distribution graph of promoting time in Figure 1, it is more intuitive to find out the promoting rules of each title. The horizontal axis represents the time when one has served at a lower title. The ordinate axis represents the proportion of getting promotion with a certain years in all promoted persons.

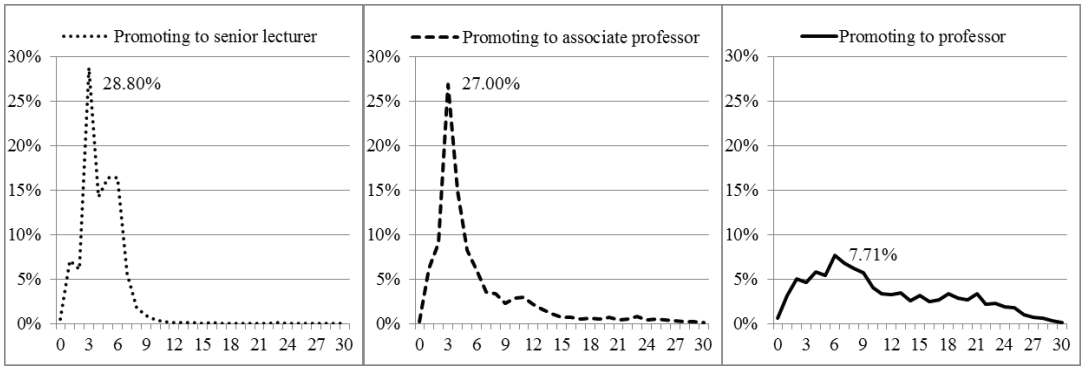

Fig. 1 The probability density distribution of promoting time

When promoting to senior researchers, the promoting peak time appears at 5 to 6 years. 7.71% senior researchers have severed as associate researchers for 6 years, and then got the promotion. After the peak period, for every additional year, the number of promoted persons has declined rapidly. While, there is a noteworthy phenomenon that during 13-21 year, the down trending stops and the number of promoted persons keeps relatively stable and fluctuated slightly. From a macro perspective, this period can be regarded as a stead period of promoting to senior researcher.

When promoting to associate researchers, there is a significant promotion peak period between 3 and 4 years. 27.00% intermediate researchers have severed as intermediate researchers for 3 years and then got the promotion. Nearly 60% associated researcher used no more than 4 years to get the promotion. After the peak period, for every additional year, the number of promoted persons has declined more rapidly. However, compared to the density curve of promoting to intermediate, there is a fat tail, especially between 7 and 13 years, the reducing speed slowed down, which means there are still a small group of intermediate researchers to be promoted during this period.

The promoting rule of intermediate researchers combines the characteristics of the associate and senior rules. Between 3 and 6 years, there is a clear peak promotion, 56.28% of lecturer have severed as intermediate researchers for 3 to 6 years and then got the promotion. Compared to intermediate researcher, this peak period is relatively longer, which indicates that there are some individual differences in lecturer. In the late promotion peak interval (5 to 6 years), the number of promoted persons stops the decline trend and keeps relatively stable and fluctuated slightly in a short time. 89.56% lecturer used no more than 6 years to get the promotion. After this period, the number of promoting people reduces sharply.

The promoting probability of each title in research positions ($P_{ij}(y)$) is listed in Table 4.

Table 4. The promoting probability of each title

Duration	Promoting to senior lecturer	Promoting to associate professor	Promoting to professor
0 year	0.23%	0.68%	0.52%
1 year	7.11%	6.26%	3.14%
2 years	6.12%	9.06%	5.06%
3 years	28.80%	27.00%	4.69%
4 years	14.25%	14.96%	5.86%
5 years	16.38%	8.31%	5.43%
6 years	16.38%	6.01%	7.71%
7 years	5.65%	3.60%	6.78%
8 years	1.82%	3.37%	6.23%
9 years	0.90%	2.27%	5.73%
10 years	2.06%	18.95%	48.71%

3.3. Results

Although the total number of the research positions in CAS has experienced a rapid growth since 2006, the growth rate reduced sharply year by year. In 2014, the growth rate of total research positions deceased to 0.67%, while the fastest growing year is in 2009 with annual growth rate of 14.33%. Therefore, we set the growth rate of total research position as 0.5%. The other index that needs to be set beforehand is the position structure of lecturer, senior lecturer, associate professor and professor. This is an index that the leader can set according to the actual situation. Given the related policies in CAS, we set the position structure of lecturer, senior lecturer, associate professor and professor as 20.00%, 37.00%, 26.00%, and 17.00%. Therefore, by the end of 2020, the overall research positions in CAS are 40487 and the number of every title is displayed in Table 5.

Table 5. Some indices of research positions used in experiment

Titles	Position Structure	Retiring rate	Separation rate
Lecturer	20.00%	0.07%	16.84%
Senior lecturer	37.00%	2.28%	5.98%
Associate professor	26.00%	5.61%	4.16%
Professor	17.00%	4.84%	2.74%

Based on the historical data in ARP, The retiring rate is calculated by averaging the annual retiring rate from 2006 to 2014. Therefore, the retiring rates of lecturer, senior lecturer, associate professor and professor are 0.01%, 0.21%, 0.85%, 0.96%, respectively. Similarly, the separation rate is calculated by averaging the annual separation rate from 2006 to 2014. The separation rates of lecturer, senior lecturer, associate professor and professor are 16.84%, 5.98%, 4.16%, 2.74%, respectively. Based on the proposed method in Section 2, the most probable number to be promoted of every year are calculated, which are list in Table 6.

Table 6. The most probable number to be promoted

Titles	2014	2015	2016	2017	2018	2019	2020
Promoting to senior lecturer	763	633	661	758	740	756	789
Promoting to associate professor	1669	1877	1693	1680	1667	1750	1759
Promoting to professor	565	520	502	579	551	552	570

By the end of 2020, when the 13th fifth five year plan ends, the final human resource demand gap is estimated as in Table 7. By analyzing the results of the final iteration, some conclusions can be drawn. Firstly, there is a big demand gap of the research position on the whole in the next five years. Thousands people are needed every year to meet the growth of research positions. Secondly, there is a great demand for lecturer and senior lecturer. In 2020, there are 2152 lecturer positions and 2293 senior lecturer positions that need to be fill the vacancy. The main reason is the high separation rate of these two titles. Thirdly, due to the regulation on position structure, the number of associate and senior titles is strictly restricted. Therefore, the estimating human resource demand gaps of these two titles are negative, indicating that some people will have to leave CAS or transfer to the managerial or supportive position.

It is noteworthy that the results in 2015 are quite different from the other years. The main reason lies in that when the first iteration is carried out, the actual data of retiree and separation in 2014 is applied. However, the actual data in 2014 is very big and different from the other historical years. Therefore, the demand gap is relatively big.

Table 7. The human resource demand gap in the 13th five year plan

Research position	2015	2016	2017	2018	2019	2020
Lecturer	5409	1991	2031	2135	2125	2147
Senior lecturer	4318	2196	2010	1904	1914	1986
Associate professor	-120	-783	-625	-531	-545	-623
Professor	-421	-238	-218	-295	-265	-264
Total	9185	3167	3198	3214	3230	3246

4. Conclusions and suggestions

Although the researcher population experienced a rapid growth in the last few years, there is a significant decline in the growth rate of researchers currently. It indicates that the total number of researchers is growing very slowly and may be saturated in the next few years. However, since the strictly limit to the position management in Chinese scientific research management, the Chinese researchers are going to face a brutal promotion stress. In addition to the fast growing tendency in the past several years, this problem is more serious. Every year, nearly five to six hundreds of associate researchers and two hundred senior researchers have to leave their positions as a result of failure to get promotion. Therefore, the current position management policies no longer meet the rapid development of researchers.

This research is just a preliminary attempt and still has limitations need further perfection. For example, some indices in the model, such as the retiring or separation rate, can be estimated more precisely, instead of simply taking the average. Besides, when estimate the people to be promoted, one's research output (papers, patents, reward and so on) can be taken into consideration.

Acknowledgement

This research is supported by National Natural Science Foundation of China (71201156), Informatization Special Funds of the Chinese Academy of Sciences (Y201711601, Y201701601) and Youth Innovation Promotion Association of Chinese Academy of Sciences.

Reference

[1] Meng F. Study on the Challenge and Future Development of Research System in China: Based on the Analysis of Academic Level of SCI Papers. *Science and Technology Management Research* 2011;**31**:236-40. (in Chinese)
[2] Marler JH, Fisher SL. An evidence-based review of e-HRM and strategic human resource management.*Human Resource Management Review* 2013;**23**:18-36.
[3] Shi E, Deng M, Jing Z, Li H, Pan J, Cao X. On the Management of Research institutes. Beijing: Science Press; 2007. (in Chinese)
[4] Chen Z, Wu D, Lu J, Chen Y. Metadata-based Information Resource Integration for Research Management. *Procedia Computer Science* 2013;**17**:54-61.
[5] Li J, Ji J, Wu D, Lu J, Sun X, Chen Y. Study on several problems of decision support models for scientific research management based on ARP. *Science & Technology for Devlopment* 2012;**10**:18-23. (in Chinese)
[6] Abernathy WJ, Baloff N, Hershey JC, Wandel S. A three-stage manpower planning and scheduling model—a service-sector example. *Operations Research* 1973;**21**:693-711.
[7] Igboanugo A. Application of Markov Chain Model to Corporate Manpower Planning: A Nigeria Local Government Hub Example. *Advanced Materials Research* 2013;**824**:514-26.
[8] Gao M, Chang H, Zhang J. Research on Pilots Strategic Human Resources Planning in Civil Aviation. *Science & Technology for Devlopment* 2012;**3**:40-6. (in Chinese)
[9] Sniedovich M. Dynamic programming: foundations and principles: CRC press; 2010.
[10] Jing H, Yang Z. Dynamic Forecasting Program for Human Resources Planning. *Forecast* 2001;**20**:23-5. (in Chinese)