A Performance Appraisal Method Based on ACP Theory and PageRank Algorithm

Xiaowei Shen Xiwei Liu(Corresponding author) Dong Fan Changjian Cheng Gang Xiong
State Key Laboratory of Intelligent Control and Management of Complex Systems
Institute of Automation, Chinese Academy of Sciences
Beijing, China
neusxw@126.com xiwei.liu@ia.ac.cn dong.fan@ia.ac.cn changjian.cheng@ia.ac.cn gang.xiong@ia.ac.cn

Abstract—**It is important for a chemical plant to find a suitable performance appraisal method. In this paper, based on the ACP (artificial system, computational experiment, and parallel execution) theory and the PageRank algorithm, a new performance appraisal method is proposed. The proposed method comprehensively involves both peoples and routine management rules from the holistic viewpoint. By comparison with the traditional performance appraisal method, the proposed method is more reasonable, more flexible and robuster.**

Keywords-Enterprise Management; Performance Appraisal; ACP Theory; PageRank Algorithm

I. INTRODUCTION

With the development of management science, production technologies and the economic globalization, human factors have gained more and more attentions by comparing with technical reconstruction. Almost all believe that the management in a chemical plant can be improved if managers make full use of the capabilities of all persons. Therefore, many companies tend to pay more attention to human resource (HR) management than financial management. How to explore the potential powers of human resources, and stimulate the enthusiasm and creativity of workers are critical issues on the company's core competitiveness [1-3].

In order to optimize the HR configuration and improve HR management, a reasonable methodology to select worker and evaluate their performance must be built. So, most of enterprises introduce various of advanced HR management approaches, such as the competency model, performance management and standardized assessment [4, 5]. The key issue of effective HR management is performance appraisal. But, unfortunately, most of the traditional performance appraisal methods, which are based on expertise, are deficient. These methods often tend to overemphasize the individual performance and ignore the overall factors [6]. That leads to several drawbacks.

First, the feature of today's production is socialized mass production, which means systematical and large-scale production. Comparing with the old-fashioned production, there exist more complex interaction between worker, machine and environment. All workers constitute an integrated entity and play a role in the production. This leads to the fact that the performance of the worker is interrelated and indivisible. So, it is not enough to appraise workers' performance without the consideration of group work as a whole.

Second, the design of the traditional performance appraisal system depends on subjective experience too much but lack in objective criteria. The establishment of the appraisal criteria as well as setting of the criteria weights is decided by the traditional routine or expertise, which is known as expert assessment method (EAM). But, in fact, the experts are all specialized in their own domain areas and can't grasp the whole context of the production process.

Lastly, because the establishment of an appraisal system often costs a long time and much money, the enterprises generally can not afford the re-establish of a new appraisal system for the high cost. But, the business and social environment, even the enterprises' own situations are continuously changing, and sequentially new requirements are put forward. Therefore, an agile performance appraisal system is required with the adapting capability to the environment.

To cope with these drawbacks, in this paper a new performance appraisal method based on ACP theory (artificial systems, computational experiments and parallel execution) and PageRank algorithm (ACPPR), is proposed. According to the ACP theory, we take all the workers in a workshop as a whole and apply the network analysis technology to the workshop organization. First, all workers are considered as a set of nodes. Then the relation of the related worker can be defined according to the workshop's daily performance records and a network is constructed. Finally, the performance levels of these workers are computed by PageRank algorithm based on the network. As a case study, we utilize the empirical data gathered up by a parallel management system (PMS) which is running in a ethylene production plant. The result shows the proposed method is useful to objectively, effectively, and roundly evaluate the organizational performance.

II. THE DESCRIPTION OF ACPPR METHOD

A. Background

The general procedure of the EAM method is:

1). Experts determine the appraisal criteria and set up the weights of those criteria based on traditional routine and expertise.

2). Plant managers investigate and review the workers'

This work is supported in part by NSFC 70890084, 60921061, 90920305 CAS 2F09N05, 2F09N06, 2F10E08, 2F10E10;

job performance from the viewpoints of criteria defined above, such as the aspects of safety, quality, equipment, discipline, productivity, efficiency, etc.

3). All the scores on the appraisal criteria are obtained, the performance level of every worker is computed [7]. Supposing there are m workers and n appraisal criteria in all, the appraisal result can be described as follow.

$$h_i = \sum_{j=1}^{n} r_{ij} \times m_j \qquad i = 1, 2 \cdots, m \qquad (1)$$

Where, h_i denotes the performance level of the i -th worker; r_{ij} denotes the mark of the i -th worker gets from the j -th appraisal criterion, and m_j denotes the weight of the j -th appraisal criterion.

We can see that, EAM evidently neglects the influence of environment and the interaction among workers. The major reason causes this is that the relationship in a workshop is too complex. The production system surely is a complex system, which includes workers in various positions, large-scale and complex machines, continuously changing environment and the complicated interactions among those elements. The EAM method is unavailable to evaluate the holistic performance of such a system.

To resolve the problems of complex system, such as industrial management, which are difficult to model or can not be modeled, Wang [8-17] creatively initiates a new methodology, ACP theory. It is also known as Parallel System Theory. ACP theory includes three parts that are artificial systems, computational experiments and parallel execution. This theory includes three steps to manage and control the complex systems. The artificial systems are firstly constructed by various models in the system, and then the computational experiments are carried out to find the property of the systems. Finally, the real and artificial systems are executed in parallel for special purpose, such as training, assessment and optimization [10].

To improve the performance appraisal system, we can firstly create an artificial systems based on the gathered data from daily records and then implement computational experiments in this system. Finally, for further optimization, we can also apply parallel execution. But, for highlighting the key points, we focus on the computational experiments.

For the relationship of the worker can be represented by network, PageRank algorithm can be used in Computational Experiments. PageRank algorithm is developed by Sergey Brin and Larry Page at Stanford University for reflect the relevance among web pages in the Internet and has become the most important trademark of the Google Inc.[18-20]. This algorithm uses the hyperlinks between web pages to determine the rank of a page, and takes a link from page A to page B as a vote page A cast to page B. Then new rank is determined according the resources and targets quality of the votes. Through iteratively implementing this procedure, the final rank of the webs can be determined. Generally, PageRank algorithm may be applied to any collection of entities with reciprocal quotations and references [21-23].

B. *The ACPPR Method*

Based on the above analysis, we propose our performance appraisal method, ACPPR, as follows.

Step 1. Take each worker as a node and each appraisal criterion as a factor determine the worker's performance level. Thus, a vector describes the individual characteristics of each worker is defined. If there are m workers and n appraisal criterion in all, there are m nodes and every node is described by a vector with n dimensions.

Step 2. Load the worker's implementation quality table recorded in daily practical operating and initializing the performance level of each worker, which usually set as $1/m$.

Step 3. Compute the similarity of every two nodes and take it as the connection weight. Hence, a relationship network is constructed.

Step 4. Appraise every node according to the performance level of its neighbors and renew the performance level of each node using PageRank algorithm.

Step 5. Iteratively do step 3 and step 4, until convergence.

On the description of ACPPR we can see the obvious feature of this method is that it retains the qualitative section of the expertise (appraisal criteria in the appraisal system), but abandons the quantitative section of the expertise (the weight of the appraisal criteria) and takes the overall structure into account for quantification.

To ensure the successful implementation of ACPPR, we must figure out the similarity between every two workers properly. For this purpose, we extend the definition of binary variables similarity and define the workers' similarity in equation (2). .

$$\omega_{ij} = \sum_{k=1}^{n} \omega_{ij}^{k} \qquad i, j = 1, 2, \cdots, m \qquad (2)$$

Where, ω_{ij}^{k} denotes the effectiveness of the k -th appraisal criterion on the similarity between i -th and j -th worker, which is defined as follow.

$$\omega_{ij}^{k} = \begin{cases} 0, & r_{ik} = r_{jk} = 0 \\ \dfrac{r_{ik} \wedge r_{jk}}{r_{ik} \vee r_{jk}}, & otherwise \end{cases} \qquad (3)$$

Where, r_{ij} denotes the mark of i -th worker gets from j -th appraisal criterion.

The iterative computation procedure of the performance level of the workers essentially is a process of mutual vote, which is primarily based on the performance level of the voter and the similarity between the candidate and the voter. So, the following inferences are obviously true.

1) The closer the similarity of two workers is, the more relative is the performance level of these two workers.

2) The higher the performance level of a worker is, the higher is the performance level of his nearby neighbors.

To guarantee the above premises, we define the modification rule of the performance level as equation (4).

$$h_i = d\sum_{j=1}^{n} h_j^{\alpha} \omega_{ij}^{\beta} + (1-d)/m \tag{4}$$

Where, h_i denotes the performance of the i -th worker; ω_{ij} denotes the similarity between the i -th and the j -th worker; d denotes the damp factor to ensure convergence; m and n respectively denote the number of workers and appraisal criteria; both α and β are constant parameter greater than zero used to regulate the weight of each variable. In order to ensure convergence, after any iteration, h_i should be normalized as equation (5).

$$h_i = h_i \Big/ \sum_{k=1}^{m} h_k \tag{5}$$

Since the relationship network of workers has been set up, according to equation (2) to (5) and proper parameter settings, the ACPPR method can be applied in the performance appraisal.

III. CASE STUDY

Maoming Petrochemical Inc. is one of the earliest and the most fruitful company in application of standardization management among china's petrochemical companies. The data in this paper is gathered from the daily performance appraisal in Maoming ethylene plant by the PMS. The PMS system is developed by Institute of Automation, Chinese Academy of Sciences based on ACP theory and has been successfully applied in petrochemical industry [10]. The data collected from January 2009 to May 2010 are composed by eight fields that are date, reviewer, job category, team number, reason, mark, character, and item label. There are totally 28 workers and 38 related appraisal criteria involved. Computing the similarity between every two workers, we can get the relationship network as shown in figure 1.

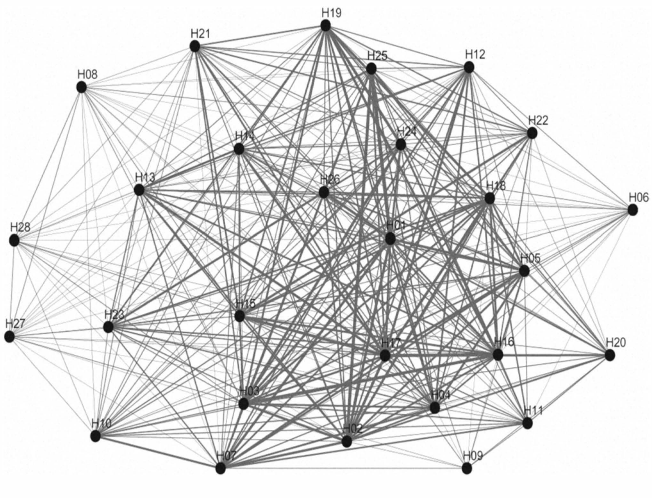

Figure 1. The Relationship Network of the Worker

Where, a dot means a worker; a line between two dots means the relationship of the two workers, and the thickness of a line shows the strength of the relationship.

TABLE I. THE PERFORMACE LEVELS COMPUTING BY AEM VS ACPPR

number	1	2	3	4	5	6	7
EAM	0.057049	0.044083	0.060679	0.039761	0.019319	0.003458	0.036736
ACPPR	0.054343	0.053609	0.052164	0.043366	0.043348	0.013442	0.044009
number	8	9	10	11	12	13	14
EAM	0.001729	0.001729	0.022042	0.039761	0.038033	0.040626	0.019449
ACPPR	0.013555	0.011401	0.027529	0.024324	0.034691	0.034953	0.033617
number	15	16	17	18	19	20	21
EAM	0.060939	0.051733	0.044083	0.067854	0.054888	0.034791	0.022042
ACPPR	0.045965	0.052831	0.064435	0.04948	0.044587	0.025553	0.029856
number	22	23	24	28	28	28	28
EAM	0.016423	0.067854	0.043435	0.001297	0.001297	0.001297	0.001297
ACPPR	0.026907	0.031029	0.040766	0.012098	0.012098	0.012098	0.012098

Then, based on the ACPPR algorithm, the performance level of every worker can be obtained, where the parameters are defined as $\alpha = \beta = 1$, $d = 0.85$. The results are shown in table 1, where the results based on the EAM are also shown. What should be pointed out is that minus marks in the original data are omitted because such data are very few.

IV. RESULT AND ANALYSIS

A. The Correlation between EAM and ACPPR

The performance levels computed by AEM and ACPPR are respectively taken as the abscissa and ordinate to compare the results, as shown in figure 2.

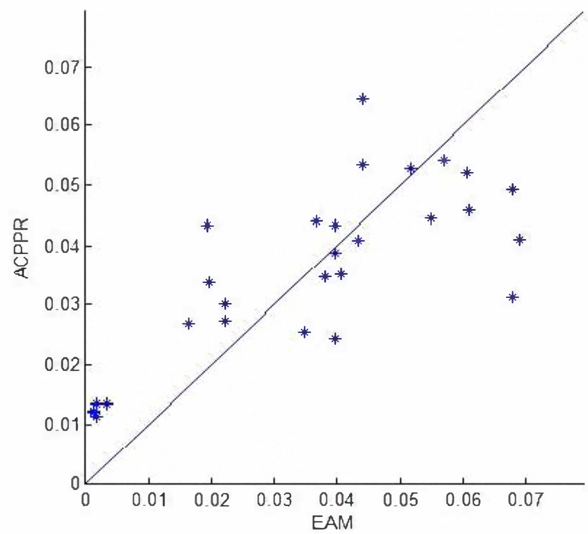

Figure 2. Scatter graph of AEM and ACPPR results

It is can be clearly seen in figure 2 that the results get from the two different methods are highly relevant. In order to further investigate their relevance, we use SPSS software to compute the Pearson Related Coefficient between AEM and ACPPR. The results are shown in Table 2.

TABLE II. THE CORRELATION ANALYSIS BY SPSS

		ACPPR	EAM
ACPPR	Pearson Correlation	1	.766**
	Sig. (2-tailed)		.000
	N	28	28
EAM	Pearson Correlation	.766**	1
	Sig. (2-tailed)	.000	
	N	28	28
**. Correlation is significant at the 0.01 level (2-tailed).			

Table 2 shows the Pearson Related Coefficient is 0.766 and the correlation is significant at the 0.01 level. So, it can be concluded that the results of the two methods are highly correlated. That means the EAM and the ACPPR are consistent in trend, which proves the validity of the ACPPR from another perspective.

B. The Advantages of ACPPR

Compared with the EAM method, the ACPPR has some obvious advantages listed as below.

First, the ACPPR takes all the workers in a workshop as a whole. It analyzes the performance of the workers from relationship viewpoint, otherwise from individual behavior viewpoint. The research on psychology and modern management sciences has shown that social ties have greater impact in the production than personal salaries. Only concerning with the individuals and neglecting the overall performance, we will tend to fail to see the whole for the part. The ACPPR method can overcome this shortcoming.

Second, the ACPPR only relies on the qualitative section and abandons the quantitative section of the expertise, the appraisal criteria are emerged from the whole relationship network. This can overcome the subjective factors in EAM. Especially, comparing with the EAM, the ACPPR can effectively reduce the management costs.

Additionally, for modern enterprises, the production environment and marketing environment are constantly changing. In order to remain survival in the fierce competition, companies should and must face these changes. Because of the time-consuming and high-cost of the EAM, which is uneasy to improve once it is built. But, for ACPPR, which are partly data driven, the change can be directly reflected from the data. So, the ACPPR are more flexible and robust to environment.

C. Further Improvements

The above sections have shown the advantages of ACPPR. But, in fact, although the EAM is undesirable because it entirely relied on the expertise, it often contains substantial prior knowledge and structural cognition about the system, which are valuable experience accumulated day by day. So, the appraisal result of EAM should not be totally denied. Based on this understanding, we improved the iterative formula (4) as shown below.

$$h_i = \delta(d\sum_{j=1}^{n} h_j^{\alpha}\omega_{ij}^{\beta} + (1-d)/m) + (1-\delta)h_i' \qquad (6)$$

Where, h_i' denotes the appraisal result gotten by EAM; δ is the pondage factor range from 0 to 1. When δ equal to 0, equation (6) degenerates to EAM, and when δ equal to 1, the equation (6) degenerates to ACPPR. As δ changing from 0 to 1, the result coordinates the two methods.

V. CONCLUSION

In this paper, a new performance appraisal method ACPPR based on ACP theory and PageRank algorithm is proposed. Comparing with the traditional EAM method, ACPPR method appraises the workers' performance through relationship network by computational experiments. This makes the appraisal result more reasonable, more flexible and robuster to environment.

REFERENCES

[1] FJ Roethlisberger, WJ Dickson, and William John Dickson, *Management and the Worker: An Account of a Research Program Conducted by the Western Electric Company, Hawthorne Works, Chicago.* Cambridge, MA: Harvard University Press, 1939.

[2] Thomas J. Peters and Robert H. Waterman, *In Search of Excellence: Lessons from America's Best-Run Companies.* London: Harper & Row, 1982.

[3] Domènec Melé, "The Challenge of Humanistic Management," *Journal of Business Ethics,* vol. 44, pp. 77-88, 2003.

[4] Jeffery S. Shippmann, Ronald A. Ash, Mariangela Batjtsta, Linda Carr, Lorraine D. Eyde, Beryl Hesketh, Jerry Kehoe, Kenneth Pearlman, Erich P. Prien, and Juan I. Sanchez, "The practice of competency modeling," *Personnel Psychology,* vol. 53, pp. 703-740, 2000.

[5] Aubrey C. Daniels, *Performance Management: Changing Behavior That Drives Organizational Effectiveness*: Performance Management Publications, 2006.

[6] "Performance Appraisal Handbook ": U.S. Department of the Interior, 2004, p. 67.

[7] Yu-min Zou, "Implementation of standardized assessment, establish benefits system and improving management level," *China Economic Information* vol. 2, pp. 72-73, 2002.

[8] Fei-Yue Wang and Shuming Tang, "Artificial Societies for Integrated and Sustainable Development of Metropolitan Systems," *IEEE Intelligent Systems,* vol. 19, pp. 82-87, 2004.

[9] Fei-Yue Wang, " Artificial Societies, Computational Experiments, and Parallel Systems: A Discussion on Computational Theory of Complex Social-Economic Systems," *Complex Systems and Complexity Science,* vol. 1, pp. 25-35, 2004.

[10] Chang-jian Cheng, Feng Cui, and Fei-yue Wang, "An Investigation of Parallel Management Information System technology based on Service-Oriented Architecture," in *Service Operations and Logistics and Informatics (SOLI), 2010 IEEE International Conference on*, pp. 342-345.

[11] Fei-Yue Wang, "Parallel control and management for intelligent transportation systems: concepts, architectures, and applications," *Trans. Intell. Transport. Sys.,* vol. 11, pp. 630-638.

[12]Fei-Yue Wang, "Parallel system methods for management and control of complex systems," *Control and Decision,* vol. 19, pp. 485-489, 2004.
[13]Fei-Yue Wang, "Computational Experiments for Behavior Analysis and Decision Evaluation of Complex Systems," *Journal of System Simulation,* vol. 16, pp. 893-897, 2004.
[14]Fei-Yue Wang, "Social computing：concepts，contents，and methods.," *International Journal of Intelligent Control and Systems,* vol. 9, pp. 91-96, 2004.
[15]Fei-Yue Wang, "On the Modeling, Analysis, Control and Management of Complex Systems," *Complex Systems and Complexity Science,* vol. 3, pp. 26-34, 2006.
[16]Nan Zhang, Fei-Yue Wang, Fenghua Zhu, Dongbin Zhao, and Shuming Tang, "DynaCAS: Computational Experiments and Decision Support for ITS," *IEEE Intelligent Systems,* vol. 23, pp. 19-23, 2008.
[17]Qinghai Miao, Fenghua Zhu, Yisheng Lv, Changjian Cheng, Cheng Chen, and Xiaogang Qiu, "A Game-Engine-Based Platform for Modeling and Computing of Artificial Transportation Systems " *IEEE Transactions on Intelligent Transportation Systems,* vol. 99, pp. 1-11, 2011.
[18]S. Brin and L. Page, "The Anatomy of a Large-Scale Hypertextual Web Search Engine," in *Seventh International World-Wide Web Conference (WWW 1998)* Brisbane, Australia, 1998, pp. 107-117.
[19]Lawrence Page, Sergey Brin, Rajeev Motwani, and Terry Winograd, "The PageRank Citation Ranking: Bringing Order to the Web," Stanford InfoLab, Technical Report1999.
[20]T. Haveliwala, "Efficient Computation of PageRank," Stanford InfoLab, Technical Report1999.
[21]Johan Bollen, Marko A. Rodriquez, and Herbert Van de Sompel, "Journal status," *Scientometrics,* vol. 69, pp. 669-687, 2006.
[22]Andrea Esuli and Fabrizio Sebastiani, "PageRanking WordNet Synsets: An Application to Opinion Mining," in *Proceedings of ACL-07, the 45th Annual Meeting of the Association of Computational Linguistics*, 2007, pp. 424-431.
[23]Gabor Ivan and Vince Grolmusz, "When the Web meets the cell: using personalized PageRank for analyzing protein interaction networks," *Bioinformatics,* vol. 27, pp. 405-407, 2010.