A fuzzy model on how the management affects a worker's state

Zhen Shen, Fei-Yue Wang, *Fellow, IEEE*, Chang-Jian Cheng, Wei-Na Zhong

***Abstract*— A worker's energy level, mood, skill level can affect her/his working performance. These factors can be regarded as the "state" of the worker and they affect the production. Also, these factors are affected by the management. In this way, the management affects the production. One important task of managing a factory is keeping the production in a high level and in a safe condition via improving the management. However, in the literature usually this is done in an exogenous way, that is, a survey is given and based on the survey result the management is improved. This paper provides a first step for "optimizing" the management in an endogenous and analytical way. We propose a framework based on which we can analyze how the management affects the state of the worker and then affects the production. The basic idea is that we regard the management as a control policy to control the state of a worker to make the worker-position fitness as good as possible. We admit that it is difficult to evaluate how the management affects the worker's state as this problem is closely related to the uncertainty rooted in the human-being. To attack this difficulty, we introduce the fuzzy method to model how the management affects a worker's state. By the method in this paper, reasonable results can be obtained, based on which the management can be improved. In the future, it may be possible to collect real data to improve the method in this paper.**

I. INTRODUCTION

USUALLY a worker's energy level, mood, skill level, etc. can affect her/his working performance. And the working performance can affect the production. For example, if a worker operates a machine for cutting for which high accuracy is required, the skill level and the energy of the work can affect her/his working efficiency and the scrap rate. In chemical engineering, a worker's energy level, mood, skill level, experience level can affect her/his operation. And then the production rate, the possibility of maloperation can be affected. A long-existing question in management science is how to keep the worker working with high efficiency and less possibility of maloperation. This problem is not easy to solve, as the worker's energy level, mood, skill level, experience level are determined by many psychology and/or physical factors. This makes it difficult to model this problem in a mathematical way. However, it is well-accepted that good management can make the workers feel good and then they can work with high efficiency. The purpose of this paper to provide a promising way to model how the management affects a worker's working. The idea is to regard the energy level, mood, skill level etc. as the "state" of the worker. In this way a worker can be seen as a dynamic system, and the state changes according to physical rules as well as is affected by the management. By taking this viewpoint, the problem can be modeled into a standard optimization problem. One big problem for modeling in this way is that uncertainty exists. It is difficult to know how good the management is, how good the state of worker is, also it is difficult to know how the management affects the state of the worker. To attack this difficulty, the fuzzy method is employed. The fuzzy method is good at modeling the relationship for which the underlying mechanism cannot be known accurately. For our problem, although it is difficult to judge how good the management is, it is easy to judge whether it is "good", "medium", or "bad". Similarly, it is easy to judge whether the energy level, the mood, the skill level are in "good", "medium", or "bad" condition. Also, we can know whether the management affects the state in a "good", "medium", or "bad" way. As a summary, we see the worker as a dynamic system, and the fuzzy method is used to "control" the system. The result can be used for feedback and then the management can be optimized.

We admit that there are defects of this modeling method. First, the model is not accurate. It is difficult for the model to give good prediction on the state of the worker. One reason is that the state may be affected by accidental events, and/or psychological/mental process. For example, a quarrel can be one of the reasons to cause a bad mood of an operator and therefore affects her/his performance negatively. It is difficult to take into account factors of this kind. Another reason is that the fuzzy method itself has model error and has difficulty in giving accurate or even correct prediction. For example, by the model, we predict that one day a worker should be in good energy condition, but the reality is that the worker is in bad energy condition. This roots in that we do not know the mechanism exactly but the fuzzy method seems to be a promising method, as explained in last paragraph. Moreover, we argue that although the prediction may not be correct, but it is still a reasonable prediction which can be used to optimize the management. In other words, although the model does not give correct prediction for a given worker, the predicted situation can appear in reality. This is why we say the prediction is reasonable. Moreover, in the future, by collecting real data to support the fuzzy model, better model and better prediction may be obtained. Second, in this model we do not consider the difference between workers. All workers are considered the same except that the initial conditions can be different. But the reality is that different workers can have different capabilities. Some can increase the skill levels very fast but some cannot. We will consider

This work was supported in part by the National Natural Science Foundation of China (NSFC) with No. 60921061 and the 2007-2009 joint project between Maoming Petroleum Chemical Company (MPCC) and Institute of Automation, Chinese Academy of Sciences.

Zhen Shen, Fei-Yue Wang, Chang-Jian Cheng and Wei-Na Zhong are with the Institute of Automation, Chinese Academy of Sciences, No. 95 Zhongguancun East Road, Haidian District, Beijing 100190, China, phone: 86-10-82615422, fax: 86-10-82615087, email: zhen.shen@ia.ac.cn.

978-1-4244-7119-5/10/$26.00 ©2010 IEEE

this in the future work. We can take some survey on the workers, and then we can know more about a worker and then we can build a more real model for her/him.

The model in this paper aims at improving the management. From another viewpoint, good management implies good person-job (or, worker-position) pair and/or good person-job fitness. One big problem to be solved for management is to determine a suitable worker for a given position. In a factory, once the pair is determined, it is costly to change the worker-position assignment. But the person-job fitness can vary over time. This is why we need to control the state of the worker, i.e., to find good management. Of course, if we can keep the worker always at good energy level, good mood, and high skill level, we do not need to improve. However this is not allowed by physical laws. People get tired at working and cannot stay working with high efficiency. This explains why we are facing an optimization problem. In this sense, there has been related research work. The person-job fit, person-group fit, person-environment fit [1-4] have been attractive topics for a long time. The researchers have a mature method of distributing and collecting surveys to related people. By the result of the survey, they can know how the fitness is, and give a method to solve the concrete problem they are facing. There is no doubt that this method can be effective. This method is an exogenous method which does not take into account the underlying mechanism. Our method in this paper is an endogenous method which focuses on the mechanism. In the future we will try to combine the endogenous method with the exogenous method to give a better method. Also, there has been much research work on fuzzy and management [5-7]. However, as far as we know, there is no method with a similar idea of this paper except [8], which is co-authored by some of the authors of this paper. In [8], the authors take the same idea that the management will affect the working in a fuzzy way, but no mathematical formulation is given. We follow their idea, and give a formulated framework on how the management affects a worker's state.

The remaining parts of the paper are organized as follows. In Section 2 we explain the motivation by a small example. In Section 3 we give the description of the framework. In Section 4 we show how to model the energy of worker in the fuzzy way, and show how the management affects the energy of worker. In Section 5 we conclude the paper and give some discussions.

II. THE MOTIVATION

As explained in Section I, the goal of management to control the state of the worker to make the worker-position fitness as good as possible. In this section, we will use a small example to explain this point in an intuitive way, and explain why fuzzy method is needed.

The worker-position fitness (or, person-job fitness) problem is closely related to the "assignment problem". In an "assignment problem", there are a number of agents and a number of tasks. Any agent can be assigned to perform any task, incurring some cost that may vary depending on the agent-task assignment. It is required to perform all tasks by assigning exactly one agent to each task in such a way that the total cost of the assignment is minimized. The key difference between assignment problem and our problem lies in the following. In the real working environment, the person-job assignment problem exists, but once assigned, it is not easy to change the assignment. However, the "cost" for the assignment varies over time, and the "output", which is the production rate, changes accordingly. Moreover, the "cost" cannot be determined accurately. Concisely speaking, the person-job fitting problem is a dynamic problem, with varying costs which cannot be known accurately.

Let's explain all the things by a two-worker, two-position assignment problem. There are two workers, A_1 and A_2, and there are two positions P_1 and P_2. We want to assign the two workers to the two positions. In the worker-position assignment, there are two possible assignments,

$$R_1 = \{(A_1, P_1), (A_2, P_2)\},$$
$$R_2 = \{(A_2, P_1), (A_1, P_2)\}. \qquad (1)$$

Case 1: (an extreme case) A_1 can only work on P_1, A_2 can only work on P_2.

For this case, there is only one feasible assignment: $R_1 = \{(A_1, P_1), (A_2, P_2)\}$. The assignment $R_2 = \{(A_2, P_1), (A_1, P_2)\}$ is not feasible. If Case 1 is the situation for a small company with only two persons, $R_1 = \{(A_1, P_1), (A_2, P_2)\}$ will be the only possible choice to make the company run.

We assume that there is a function $F(A, P)$ to measure how good a worker can work on a position, then, different assignments will have different costs, and optimization is needed. We have,

$$F(A_1, P_1) = 1, F(A_2, P_2) = 1;$$
$$F(A_2, P_1) = 0, F(A_1, P_2) = 0. \qquad (2)$$

If we have a function $G(R)$ to measure the performance of the company, accordingly, we have,

$$G(R_1) = 1; \quad G(R_2) = 0. \qquad (3)$$

In this way we describe the extreme case well. Of course, the performance of the company is affected by many factors, such as the randomness or uncertainty. Here we just take a simple way of $G(R)$ function. It is reasonable as the assignment does affect the production in the real world.

The above is a "death or alive" situation. However, one person may be able to work on several positions, and then the case is different. There is some position s/he is good at, and there is some position s/he is not good at. If we assume that the cost can be known, the problem becomes the "assignment problem".

Case 2: (the assignment problem) two persons can work on both tasks, the costs are different.

We can set up the following:

$$F(A_1, P_1) = 0{,}8, F(A_2, P_2) = 0.7;$$
$$F(A_2, P_1) = 0.2, F(A_1, P_2) = 0.3. \qquad (4)$$

And, we assume that

$$G(R) = \frac{1}{|R|} \sum_{(A_i, P_j) \in R} F(A_i, P_j), \qquad (5)$$

where $|R|$ stands for the cardinality of R. This function is made up to show how the assignment can affect the production. With this function, the more suitable a worker is for a position, the better the performance is. Then, we have,

$$G(R_1)=\frac{1}{2}(F(A_1,P_1)+F(A_2,P_2))=\frac{1}{2}(0.8+0.7)=0.75,$$
$$G(R_2)=\frac{1}{2}(F(A_2,P_1)+F(A_1,P_2))=\frac{1}{2}(0.2+0.3)=0.25. \quad (6)$$

However, the real situation in a factory can be more complex.

Case 3: (person-job fit) the assignment has been determined, but the cost varies, and it is difficult to obtain the cost accurately.

The cost is difficult to obtain, because it is difficult to know the energy level, the mood, the skill level of the workers, and it is difficult to know how these factors take effect on the person-job fitness and then how they affect the production. But we argue that with the fuzzy concept, we can still do something. We can judge whether the fitness is "good", "medium" or "bad. We will explain more in next section.

In Case 1, the concepts can be seen as "crisp". A_1 belongs to the set of people who can work well on position P_1, while A_2 does not. A_2 belongs to the set of people who can work well on position P_2, while A_2 does not. In Case 2, it is a kind of "matching degree", which is similar to the degree of membership in the fuzzy theory. For Case 3, our idea is that we keep the fuzzy concept, and the calculation will be based on the fuzzy concepts. We can use "good", "medium", "bad" as the final results, which are not accurate but can give the idea of how good the result is. This explains why the fuzzy method is needed.

III. The Model on How the Management Affects a Worker's State

In this section, we give the framework on how the management affects a worker's state. We see the management as a pool of rules. These rules not only affect the energy level, the mood, the skill level of the worker, but also can conform the behavior of the worker, the process of work, and can set up the goal of work.

We take the management rules of Maoming Petroleum Chemical Company (MPCC, http://www.mpcc.com.cn) as an example. MPCC is the largest ethylene producer of China. It is a child company of Sinopec. They have a heavy book of the summary of the rules which management the people. We give some examples in Table I.

TABLE I
SOME MANAGEMENT RULES OF MPCC

No.	*Management Rules*
1	Arrive 15 min earlier before the task begins
2	Do not smoke or drink when at work
3	Obey the order by people of higher level
4	Examine the equipment routinely
5	Take the training organized by the company
6	Reject wrong orders
7	Operate carefully, do not make the pipe jammed

We take the viewpoint of [8], which summarizes the management rules into four aspects. The first aspect includes the rules that affect the attribute of a worker. The attributes of the workers include the responsibility awareness, the safety awareness, the skill level and the energy level, etc. The second aspect is the behavior of the worker, including "discover", "inspect", "handle", "obey", "learn", etc. The third aspect includes rules that affect the process of the work. The fourth aspect includes rules setting up the goal of the work. For example, the rule "reject wrong orders" belongs to the attribute of the worker. It affects the "responsibility awareness, and the "safety awareness". The rule "arrive 15 min earlier before the task begins" affects the "responsibility awareness" and the behavior of the worker. The rule "operate carefully, do not make the pipe jammed" affects the "behavior", "the process of the work" and "the goal of work". These four aspects all affect the production. Please see Fig. 1.

Here in this paper, we view the "attribute" of a worker as equal to the "state" of the worker. If the rules belonging to the other three aspects are violated, we say that the worker maloperates, i.e., the worker makes a mistake[1].

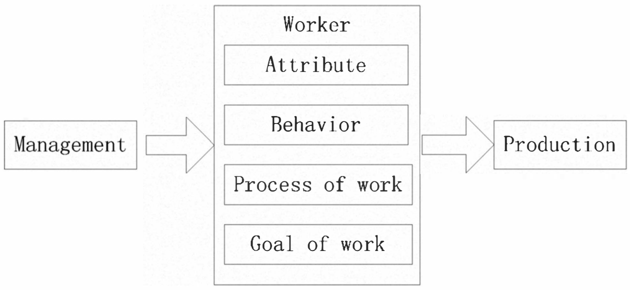

Fig.1 How the management affects the workers and then the production

After explaining our viewpoint what the management is. We give the model on how the management affects a worker's state. Although management has a wide meaning, in this paper, we take a narrow meaning of management, that is, the management is the "control over people", and control is the "control over the machine". As a first step, we take the production rate[2] as the single objective function to optimize. We can write the function as follows,

$$R = f(C, M), \quad (7)$$

where R is the production rate, and C is the control (policy) over the machines (which do not involve the people's operation), and M stands for the management of the people. This function does not involve time directly. The time issue has been considered in the function $f(C, M)$.

In modern factories, many tasks can be finished by machines automatically, so we use C to refer to the control over these machines. Also, there are tasks for which people's operation is required. For these tasks, the energy level, the mood, the skill level affect the quality of the accomplishment of the task. A better control can lead to high production rate. How to find a good control for a machine/factory has been considered a lot in the literature and usually can be seen as a separate problem, so in this paper we do not address how to control the machine. We focus on how to find good

[1] If we take a wide meaning of the state, all the four aspects can regarded as the "state" of the worker. We can introduce the concept of "degree" to describe how well a worker follows the rule. The degree can be seen as a component of the state.

[2] Currently, we set the production rate as the single objective. In the future, the safety issue can be included into the objective function.

management. Usually the management of the people is a pool (set) of rules, expressed by natural languages. In this paper, we assume that there are a set of management rules. Some of the rules are good, but some are bad; some are necessary, some are not necessary. For example, "arrive 15 min earlier before the task begins" can be a good rule, but "arrive 30 min earlier before the task begins" may not be necessary. We use Θ to denote the set of the management rules. And we use M to denote a subset of Θ. What we want to do is to select a subset M for this set of rules, and then we use this selected subset as the management of the factory. We have

$$\begin{aligned} &\max \quad R(M) = f(C,M)) \\ &s.t. \quad M \subseteq \Theta, \quad C \text{ const} \end{aligned} \tag{8}$$

This is a static point of view. The complex mechanics of the machine and the interaction between the people and the machines are summarized into the function $f(C, M)$. This function may be estimated by the fuzzy method or the neural network and is left for future work.

We go one step further to elaborate the model. We take a dynamic point of view, that is, the management affects a worker's state, and the state affects the production. As explained above, the management rules can be divided into four aspects. We argue that the attribute aspect namely the state of the worker is the critical for the other three aspects. Whether the "behavior" exists or not, whether the "process of work" is followed or not, and whether the "goal of work" is achieved or not depend on whether the worker is in good energy condition, whether s/he is skilled enough, whether s/he is aware of the safety issue. In other words, the "state" is in some sense controllable. The "behavior", "process of work", "goal of work" cannot be controlled directly. Rules are set up for the workers to obey, but due to the accidental, physical or mental reasons, the rules are not followed, as discussed in Section I. However, by controlling the state, people are likely to obey the rules. This is why the state is important. We use X to denote the state of a worker, we have,

$$\begin{aligned} &\max \quad \sum_{i=1}^{t} R_i(M) = g(C, X_i(M)) \\ &s.t. \quad M \subseteq \Theta, C \text{ const}, X_0(M) \text{ given} \\ &\qquad X_{i+1}(M) = T(X_i(M)), \quad i = 0,1,2,\ldots,t-1 \end{aligned} \tag{9}$$

In (9), $g(C, X_i(M))$ stands for function of how the state and the control affect the production, and $T(\bullet)$ is the transition rule of the state. Similar to $f(C, M)$ in (8), $g(C, X_i(M))$ could be estimated by the fuzzy method or neural network. This is left for future work. By (9), we describe a multi-stage optimization problem. Usually in a factory, the workers go through work-rest cycle. Every "working period" can be seen a stage.

In this section, we model the management as rules, and these management rules can be divided into four aspects: the attribute, the behavior, the process of work and the goal of work. The attribute can be regarded as the state of the worker. The management affects the state, and the state is controllable to affect the other three aspects, and then the production is affected. We admit that the model is simple in that the mental factor and the accidental factor are not considered in this model. This has been discussed in Section I. However, the research in this paper provides a stepping stone for further research. Probably the problems discussed in Section I can be solved properly in the future.

IV. A Study on the Management and the Energy of the Worker

In this section, we show how the management can affect the energy level of a worker in the fuzzy way. The energy level belongs to the attributions aspect, and is a component of the state vector. The purpose of this section is to show how the management affects a worker's state. The energy may be simplest component to model. That is why we choose it at the starting point of this research. The energy changes naturally as the time goes. Also, it is affected by the management rules. Good management can make people feel comfortable, while bad management can make people depressed and lose energy fast. It is difficult to measure the energy accurately. We use the fuzzy method to model the energy.

TABLE II
THE MANAGEMENT RULES THAT AFFECTS THE ENERGY

No.	*Management Rules*	*Effect*
1	Take part in the activity organized by the company	Obvious
2	Concern the group, and help each other	Medium
3	Do not be late, and do not leave early	A little

We use E to denote the energy. Please see Table II, which shows the management rules that can affect the energy of the people. Although the rules are effective all the time, we can think that the management rules are emphasized once in every period, i.e., the rules can be regarded to take effect periodically. For the rule with No. i, we assume that it takes effect every T_i time. In this paper, we assume that the energy goes less and less at work. And we assume that there are 5 groups of workers, and they take turns. There are three turns in 24 hours, 8:00- 16:00, 16:00-24:00, 24:00- 8:00 respectively. In this way, a worker works for 8 hours and then rests for 32 hours, and works for 8 hours again, and rests for 32 hours, and goes on. This is the true situation in MPCC.

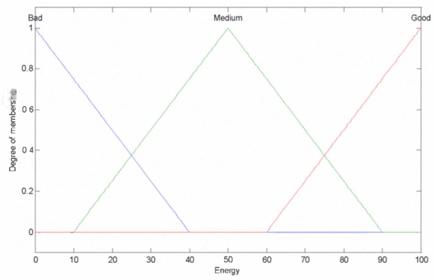

Fig. 2 The membership function of the energy of a worker

Next we go into the details. The value of the energy E is assumed to take the value in [0, 100]. When $E = 100$ it means that the worker is in very energetic, and s/he can work with high efficiency; when $E = 0$ it means that the worker is very tired and can hardly continue work. The membership function of the energy is shown in Fig. 2. We fuzzify the management rules. Please see Fig. 3. The management rules are given scores among [0, 100] and the score reflects how good the management rule is. The management rules will affect the energy. The energy change is denoted by ΔE. Please see Fig. 4. We assume that there is a heavy task periodically, which can make the energy drop fast. A score among [0, 100] is given to reflect how heavy a task is. The membership function is given in Fig. 5. The membership function of the affection of the heavy task is shown in Fig. 6.

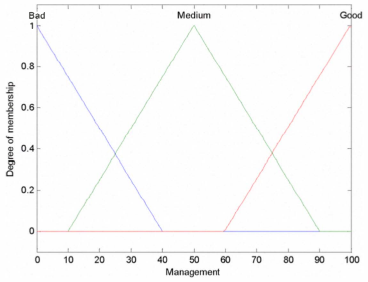

Fig. 3 The goodness of the management rules

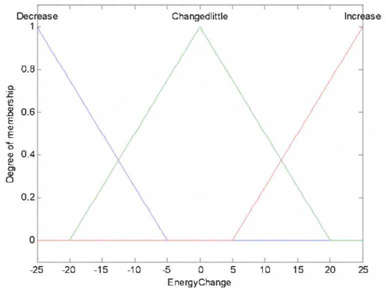

Fig. 4 The energy change by the management

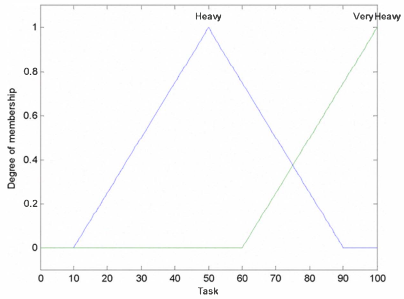

Fig. 5 The heaviness of the task

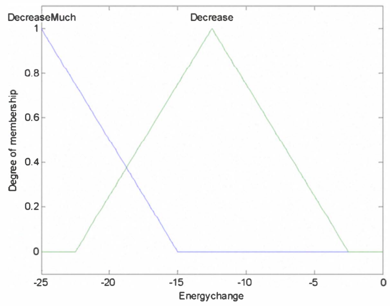

Fig. 6 The energy change by the heavy work

The rules are given in Table III. We have assumed that the management rules or the heavy task takes effect periodically. Now we further make assumptions on how they take effect. We assume that an additive value given to the energy at first, and then the effect goes weaker and weaker in a linear way. We use S to denote the strength. Please see Fig. 7. S can be positive or negative, depending on how the energy is affected. For example, if by the fuzzy method, we obtain the affection on the energy is of the value S, we will give an additive value shown as in Fig. 7 to the energy value from the time the affection takes effect.

Next we show some results. Firstly we consider the case the energy changes naturally. We set that the decrement of the energy value at work is ΔE_1 = -60, and the increment of the energy value after rest is ΔE_2 = 60. The initial value of the energy is set as E = 80. Then the change of the energy is shown in Fig. 8. We see the energy value go down and up, and down again, which is a reasonable result.

TABLE III
IF-THEN RULES

No.	*IF*	*THEN*
1	The management rule is good	The energy goes up
2	The management is medium	The energy changes little
3	The management rule is bad	The energy goes down
4	The work is heavy	The energy goes down
5	The work is very heavy	The energy goes down a lot

TABLE IV
SOME ASSUMPTIONS

No.	*IF*	*THEN*
1	After working for a fixed time	The energy goes down by ΔE_1
2	After resting for a given time	The energy goes up by ΔE_2
3	Every T_i time (i = 1, 2, 3)	The management rule i takes effect
4	Every T_{hl} time	There is a heavy task

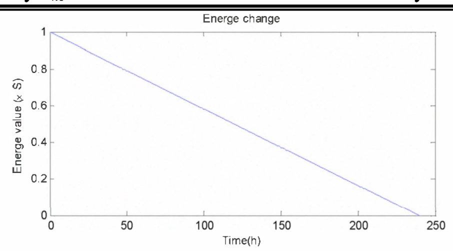

Fig. 7 The effect of a management rule or a task

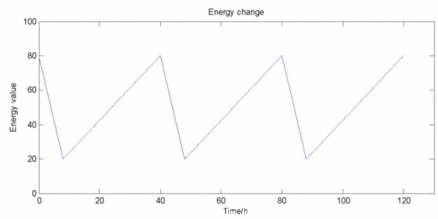

Fig. 8 The natural change of the energy

We assume that the periods for the management rules in Table III to take effect are respectively T_1 = 720 hours (30 days), T_2 = 360 hours (15 days), and T_3 = 360 hours (15 days). The strengths on the energy are respectively S_1 = 18, S_2 = 12, S_3 = 6 (correspondingly the goodness scores of the management rules are 89.9, 85.5 and 77.9). The energy change in 2000 hours (83 days and 8 hours) is shown as Fig. 9. For the first 720 hours, we do not use the management rules. This is used for contrast to show the effect of the management rules. Please note that due to the management rules, the energy value may go beyond 100. We take a cap for the energy and make it no more than 100. This is reasonable because there should be a saturation value for the energy. From Fig. 9, we see that when the management rules take effect, there is sudden increase on the energy and then the energy goes back to normal gradually. If we only consider the heaviness of the task, please see Fig. 10, which is the energy change with 2000 hours. Similarly, for the first 720 hours there is no heavy task. The strength is assumed to be S_h = -16 (the heaviness score of the task is 79.6). There is sudden decrease on the energy and the energy goes up gradually. If we consider both the management rules and the heavy task, the result is shown in Fig. 11. The first 720 hours is for the natural change. After we obtain the value for the energy, we can obtain whether the energy is good, medium or bad by the membership function of the energy given by Fig. 2.

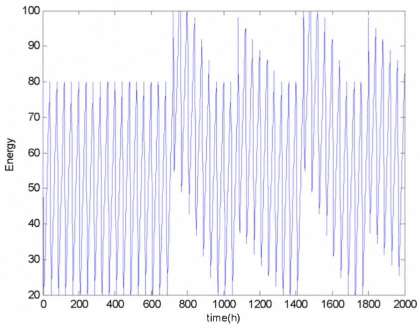

Fig. 9 How the management rules affect the energy

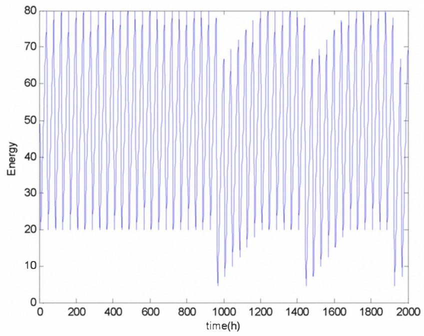

Fig. 10 How the heavy task affects the energy

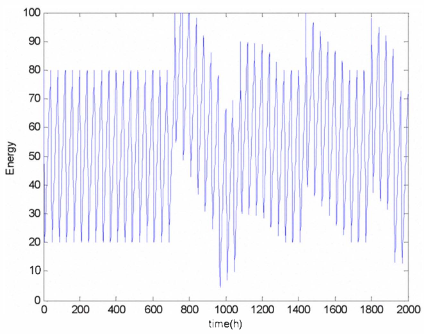

Fig. 11 How the management rules and the heavy work affect the energy

V. Conclusion and Discussion

In this paper, we propose a framework in which we model how the management affects a worker's state. The state refers to the energy level, the mood, the skill level, etc. of the worker. The management is regarded as a pool of rules, and the rules can affect the states of the workers. The goal of the management is to control the state of the worker, to make the worker as suitable for the position as possible. And, guided by this idea, we give a preliminary study on how the management affects the physical energy of a worker. Although it may not be accurate, the results obtained by the method in this paper are reasonable. We may be able to improve the model, and it may be possible to improve the management following the research in this paper.

The research in this paper is closely related to the ACP theory[9]. "A" stands for "Artificial system", "C" stands for "Computational experiments", and "P" stands for "Parallel execution". ACP is a methodology for solving problems of complex systems. When facing a problem, at first an "artificial system" is built, and then the "computational experiments" are done on the "artificial system", and then the result from the computational experiments is applied to the real situation. In this paper, the modeling on how the management affects a worker's state is the "A" part. The calculation of the "energy" belongs to the "C" part. If in the future, we can apply the optimized management to the real situation, we arrive at the "P" part. It can be said that the research in this paper is guide by the ACP theory. There are many things to be done in the future, including: 1) How to use the real world data to improve the model in this paper. 2) Extend the result to the many workers case, and the group case. 3) How to optimize the management rules automatically. 4) How to give the function between a worker's state and production rate.

Acknowledgment

The authors thank Dr. Xi-Wei Liu of Institute of Automation, Chinese Academy of Sciences for helpful discussions.

References

[1] A. L. Kristof-Brown, R. D. Zimmerman, E. C. Johnson, "Consequences of individuals' fit at work: a meta-analysis of person-job, person-organization, person-group, and person-supervisor fit," *Personnel Psychology*, Vol. 58, pp. 238-342, 2005.

[2] K. J. Lauver and A. Kristof-Brown, "Distinguishing between employees' perceptions of person-job and person-organization fit," *Journal of Vocational Behavior*, Vol. 59, pp. 454-470, 2001.

[3] A. L. Kristof, "Person-organization fit: an integrative review of its conceptualizations, measurement, and implications," *Personnel Psychology*, pp. 1-49, 1996.

[4] J. H. Greenhaus and A. G. Bedeian, "Work experiences, job performance, and feelings of personal and family well-being," *Journal of Vocational Behavior*, Vol. 31, pp. 200-215, 1987.

[5] I. Giannoccaro, P. Pontrandolfo, B. Scozzi, "A fuzzy echelon approach for inventory management in supply chains," *European Journal of Operational Research*, Vol. 149, pp. 185-196, 2003.

[6] A. L. Guiffrida and R. Nagi, "Fuzzy set theory applications in production management research: a literature survey", *Journal of Intelligent Manufacturing*, Vol. 9, pp. 39-56, 1998.

[7] Kiyoji Asai, *Fuzzy systems for management,* Ios Pr Inc. 1995.

[8] W-N Zhong, C-J Cheng, F. Cui, F-Y Wang, B. Shen, "Calculation and evaluation management ordinance for the process industry on artificial system," *Proc. of the first Chinese Conference on Parallel Management*, Beijing, Dec. 2009. (in Chinese, English abstract available)

[9] Fei-Yue Wang, "Toward a Paradigm Shift in Social Computing: The ACP Approach," *IEEE Intelligent Systems*, Vol. 22, No.5, pp. 65-67, 2007.