USING ANALYTIC HIERARCHY PROCESS TO SYNTHETICALLY EVALUATE LABOUR INTENSITY OF JOBS

Rongfang Shen, Zonghao Gu, Xiaomin Meng, Yufeng Yan
School of Economics and Management, Tongji University
Shanghai, The People's Republic of China, 200092

ABSTRACT

In this paper, Analytic Hierarchy Process is used to construct the synthetical evaluation model of labour intensity of jobs. We devide the factors into quantitative and qualitative factors. To deal with qualitative factors, the method of pair comparision is used to get the weight of ordering. To deal with the quantitative factors, this paper introduces how to use equipments and calculation formulas to measure and take it as the weight of ordering directly. Then, synthesize the both quantitative and qualitative factors to obtain the total evaluation of labour intensity. Usually group judgement is used in this situation, that is, many people take part in the judgement, according to each judgement, a set of ordering weights and consistent indexes can be obtained. The authors propose a new method of using consistent index to weight all of the ordering weights in order to determine the ordering weight of group judgement. Practically, concerning the characters of labour intensity, two-class synthesis evaluation is applied. We used to evaluate some jobs in building industry appling the method mentioned above, the result is quite satisfactory.

1. INTRODUCTION

The phenomena of strong labour intensity, bad working environment, many accidents and inconsistency between labour intensity and salary are present in Chinese building industry. All of these phenomena influence finishing production tasks and are also unfavourable to raising worker's technical competence. Therefore, correctly and totally evaluating labour intensity can not only rationalize remuneration, but also raise worker's enthusiasm and productivity.

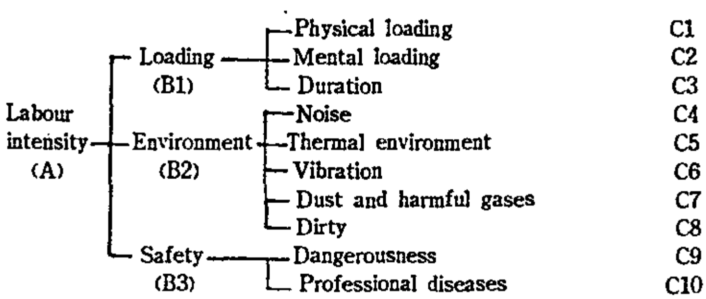

Figure 1. The model of labour intensity evaluation by AHP

There are three main factors which influence the labour intensity considered: loading, environment, safety. They can be devided more detailed into: physical loading, mental loading, duration, noise, thermal environment, dust and harmful gases, dirty, dangerousness and professional diseases, etc.. The authors construct the synthetical evaluation model of labour intensity by AHP (Fig. 1).

2. THE FACTORS WHICH INFLUENCE THE LABOUR INTENSITY

As shown in Figure 1, there are 10 factors which effect the labour intensity, including some quantitative factors (which can be calculated or measured by formulas and equipments, such as noise, etc.), some quantitative factors (which is very hard to be measured directly). Whether a factor is qualitative or quantitative depends on the present situation, for example, if we have no sound level meter, we determine the noise relative values by pair comparision. In this case, the factor is quantitative.

In this paper, the ten factors mentioned above are devided as follows: Qualitative: mental loading, duration, dirty, dangerousness and professional diseases. Quantitative: physical loading, noise, thermal environment, dust and harmful gases and vibration.

To the qualitative factors, we can make pair comparisions according to the meaning of each factor, so we are not going to give the details about this. We will concerntrate on how to measure the quantitative factors.

2.1 Physical loading

Physical loading reflects worker's energy consumption in the physical strength during work. The method measuring heart rate has been used to determine intensity grade of physical loading. The formulas are as follows:

$$X = (N \times t)/480 \quad (1)$$

$$M = 4.43 \times 10^{-4}(72+X)^2 \quad (2)$$

$$I = 3T+7M \quad (3)$$

where X = average increasing heart rate of total working day, beat/min.

N = increasing heart rate of every measure, beat/min.

t = time interval of measure, min.

M = energy consumption of physical load

T = working time rate

I = index of physical load

2.2 Noise

We used equivalent continuous sound pressure level A (Leq) to evaluate the intensity of noise (Formula (4)).

$$Leq = 10 \lg \left(\frac{1}{t1-t2}\int_{t2}^{t1} 10^{L(t)/10}\, dt\right) \quad (4)$$

where Leq = equivalent continuous sound pressure A, dB(A)
L(t) = sound pressure A, dB(A)

2.3 Thermal environment

Thermal environment includes mainly three factors: air temperature, humidity and air flow. We use effective temperature to represent the three factors, the determination of this value can refer to (2), Fig. 29. The synthetical evaluation of thermal environment in different working days can be obtained by following formula:

$$VT = \sqrt{\frac{1}{9L}\sum_{i=1}^{L}\left[\frac{ET(i)-25}{C(i)}\right]^2} \tag{5}$$

where VT = evaluating index of thermal environment
L = number of working days
ET(i) = effective temperature of the ith working days
C(i) = 1, if ET(i)>25; C(i)=2, if ET(i)<25

2.4 Dust and harmful gases

Unfavourable factors of gas environment are mainly industrial dust and harmful gases. The harm of these substances to human body depends not only on their properties but also on their contents in air. So here eight hours equivalent concentration is used as index to evaluate concentration of a harmful substance.

$$C(i) = (Ca\cdot ta + Cb\cdot tb + \cdots + Cn\cdot tn)/8 \tag{6}$$

where C(i) = 8 hours equivalent concentration of harmful substance i, ppm.
Ca, Cb, ···, Cn — different concentration, ppm.
ta, tb, ···, tn — different concentration, h.

If there are 2 or more than 2 harmful substances, then

$$R = \sum_{i=1}^{m} C(i)/A(i) \tag{7}$$

where R = synthetic equivalent concentration, Rmax = 1
A(i) = limit value of concentration of harmful substance i
m = number of harmful substances

2.5 Vibration

Mechanical vibration is also a negative environmental factor. Influence of mechanical vibration depends on its frequency and acceleration. In this paper, K–value is used to evaluate continuous mechanical vibration. It can refer to (3), Fig. 4.4–13.

3. DETERMINATION OP THE WEIGHT OF FACTORS

According to the AHP model in Fig. 1. We made the questionaires of the factor pair comparision. 80 questionaires were handed out. 73 were back, in which 68 were effective and 5 were ineffective after being analysed. So we determined the weight according to the 68 effective questionaires. This is the problem of group judgement. We obtain the weights by two steps:

(1) to get the individual judgement weights of all factors and relative consistent index from the individual judgement;

(2) to get the synthetical weights of group judgement of all factors.

Step 1. The determination of the weight of individual judgement

It can be shown as the Fig. 1, there are A, B, C three levels, the weight calculation includes not only the weight under single criterion, but also the combinational weight.

(1) The calculation of relative weight and consistent test under single criterion.

Suppose there are n elements, B1, B2, ···, Bn under criterion A we compare the all pairs of Bi and Bj, then we get the judgement matrix, according matrix theory, we can obtain the maximum eigenvalue lmax and corresponding eigenvector W, W is the relative weight. The consistency can be tested by following formula:

$$CI = (lmax-n)/(n-1) \tag{8}$$
$$CR = CI/RI \tag{9}$$

where CI = consistent index

I = random average consistent index (the value of RI can be found in (6), page 9.)

When CR<0.1, the judgement is considered acceptable.

(2) Combinational weight of all the levels and their consistent test

In order to get the relative weight to the global goal of all the factors on each level, it is necessary to combine the calculation results under the single criterion in a certain way and to carry out the consistent test of global judgement. This process is going on from the top to the bottom in the model and level by level. Suppose we have already calculated out element's combinational weight vector of the (k−1)th level relating to the goal: $a(k-1) = \{a(k-1,1), \cdots, a(k-1,m)\}$, the weight vector of kth level relating to the jth element in (k−1)th level is $b(k,j) = \{b(k,j,1), \cdots, b(k,j,n)\}$. Let $B(k) = \{b(k,1), \cdots, b(k,m)\}$, then the weight vector of the n elements in kth level is given by:

$$a(k) = B(k) \cdot a(k-1) \tag{10}$$

To test the consistency of the hierarchy combination judgement, we have to calculate CI similarly. Suppose we have already got the result of the (k−1)th level CI(k−1), RI(k−1) and CR(k−1), the values of the kth level are:

$$CI(k) = \{CI(k,1), \cdots, CI(k,m)\} \cdot a(k-1) \tag{11}$$

Step 2. The determiation of the weight of group judgement

As mentioned above, the 5 questionaires are ineffective because of its CR>0.1. In fact, the larger the CR is, the worse the reliability of the questionaire is, and the lower of value of the judgement is. This should be taken into account when group judgement works. So we suggest to determine the weight by following formula:

$$W = \frac{1}{k}\sum [0.1-RI(i)]\, w(i) \tag{14}$$

where $k = \sum [0.1-RI(i)]$

The meaning of this formula, actually is to weight the each judgement so as to get the weight of the group judgement. When $RI(i) > 0.1$. the judgement is invalid. So, in the above formula, $[0.1-RI(i)]>0$ is right forever.

Calculating the 68 effective questionaires by formula (14), we get the weight of the C level: W=(0.124, 0.040, 0.082, 0.065, 0.083, 0.207, 0.064, 0.059, 0.181, 0.095).

4. THE AHP EVALUATION MODEL OF LABOUR INTENSITY

Fig. 1 shows the AHP model of labour intensity. As mentioned above, the C level of the model has 10 factors, in which five are qualitative and five are quantitative. To deal with the quantitative factors, we can measure them directly to get the value of each factor, and then get the ordering weight after the vector is unitized. To deal with the qualitative factors, we can get the ordering weight by pair comparision and eigenvector method.

Now the next problem is to evaluate synthetically. Synthetic evaluation has one–class and two–class method. The formula of one class synthetic evaluation is:

$$w(i) = \sum_{j=1}^{n} a(j)\cdot w(i,j) \tag{15}$$

where $w(i)$ = the ordering weight of the ith job.
$a(j)$ = the ordering weight of the jth factor.
$w(i,j)$ = the ordering weight of the ith job to the jth factor.

The above formula takes assumption of the averageness of synthetic evaluation to one–class ordering weight. But the factors of labour intensity is not always in such situation. For example, the physical loading of a certain job is so important that all the other factors is almost neglectable, in this situation , the distribution of the weight is unreasonable according to (15). So we need to use the two–class evaluation.

$$D1(i) = \sum_{j=1}^{n} a(j)\cdot W(i,j) \tag{16}$$

$$D2(i) = \max\{w(i,j)\},\quad (1<j<n) \tag{17}$$

$$CI(k) = [RI(k,1), \cdots, RI(k,m)]\ a(k-1) \quad (12)$$

$$CR(k) = CR(k-1) + CI(k)/RI(k) \quad (13)$$

If $CR(k)<0.1$, the result is considered satisfactory in the kth level.

Taking a questionaire as an example, now we are going on the calculation of weight factors and the consistent index. A questionaire actually is a table of pair comparisions between factors. As shown in Fig. 1, we can obtain four judgement matrixes under the global goal A, element Bl, B2, and B3, then we can get the relatative weight and consistent index (table 1—4).

Table 1. judgement matrix 1

A	B1	B2	B3	Priority
B1	1	1	1	1/3
B2	1	1	1	1/3
B3	1	1	1	1/3

Imax=3, CI=0, CR=0.

Table 2. judement matrix 2

B1	C1	C2	C3	Priority
C1	1	5	2	0.594
C2	1/5	1	1/2	0.128
C3	1/2	2	1	0.276

Imax=3.0055, CI=0.0028,
RI=0.052, CR=0.0054

Table 3. judgement matrix 3

B2	C4	C5	C6	C7	C8	P
C4	1	1/2	1	1/3	1	0.124
C5	2	1	2	1/2	2	0.234
C6	1	1/2	1	1/3	1	0.124
C7	3	2	3	1	3	0.394
C8	1	1/2	1	1/3	1	0.124

Imax=5.10. CI=0.0025,
RI=1.12, CR=0.0022

Table 4. judgement matrix 4

B3	C9	C10	P
C9	1	2	2/3
C10	1/2	1	1/3

Imax=2, CI=0, CR=0

According to the formulas (10), (11) and (12), the combination weights of every factors in C level to the global goal and the consistent indexes have been calculated (Tab. 5). Because $CR(2)<0.10$, the judgement is acceptable.

Table 5. combination weights of all factors in C level

A		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
B1	1/3	0.594	0.128	0.276							
B2	1/3				0.124	0.234	0.124	0.394	0.124		
B3	1/3									2/3	1/3
Priority		0.198	0.043	0.093	0.041	0.078	0.041	0.132	0.041	0.222	0.111

CT(2)=0.0018, RI(2)=0.547, CR(2)=0.0033

$$w^*(i) = k \cdot D1(i) + (1-k) \cdot D2(i), \quad (0<k<1) \tag{18}$$

Unitizing $w^*(i)$, we can get the ordering weights of factors.

We practice the method to 5 jobs in a building company: excavating earth (J1), building bamboo frame (J2), building wall (J3), mechanical whitewashing (J4) and concreting (J5). To the quantitative factors, such as noise, Leq(A) measured by sound pressure meter are 75, 75, 75, 85, 90. Because the influence to physical work can be neglected when noise is below 70dB, all the values are minused 70 and unitized, we get 0.1, 0.1, 0.1, 0.3, 0.4. These are the ordering weights. Similarly we can get the 4 quantitative factors (Tab.7). To deal with the qualitative factors, pair comparision and eigenvector method are used. For example, the judgement matrix and the weight of dangerousness are obtained from pair comparision of a certain questionaire(Tab.6). Using the group judgement which we mentioned above to synthesize the weight, we can get the vector (0.13, 0.35, 0.15, 0.17, 0.20).

Table 6. judgement matrix

C9	J1	J2	J3	J4	J5	Priority
J1	1	1/7	1/5	1/3	1/6	0.04
J2	7	1	7	4	5	0.54
J3	5	1/7	1	2	1/5	0.11
J4	3	1/4	1/2	1	1/2	0.09
J5	6	1/5	5	2	1	0.23

Similarly, we can get the ordering weight of other 4 qualitative factors, and then using the two—class synthetic evaluation get the global ordering weight of labour intensity on each job (Tab. 7).

Table 7. synthetic evaluation of labour intensity for the 5 jobs
(k=0.7, all values of this table are enlarged 1000 times)

W \ C / J	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	D1	D2	$W^*(i)$	W(i)
	124	40	82	65	83	207	64	59	181	95				
J1	310	100	140	100	210	140	140	180	130	150	164	310	208	174
J2	150	170	150	100	220	140	130	120	350	160	186	350	235	196
J3	160	240	200	100	220	150	180	150	150	190	167	240	189	158
J4	180	240	230	300	140	270	350	330	170	300	239	350	272	228
J5	200	250	280	400	210	300	200	220	200	200	244	400	291	244

From the Table 7, we find that the synthetical labour intensity of concreting is the weightest, the relative value reaches to 0.244, mutiplying by 5 (5 jobs) is equal to 122%, that means its labour intensity is 22% higher than the average intensity of the 5 jobs.

5. CONCLUSION

According to the report from the building company, the result of evaluation to labour intensity in building industry using the method mentioned above, is quite satisfactory. It can be used as the dependence of payment. Comparing with the one–class evaluation (Tab. 7, column D1), the two–class evaluation (Tab. 7, column W(i)) is more realistic.

The method mentioned in this paper also can be used in other industry. Surely the model should be modified according to real situation, and further more, the deviding of quantitative and qualitative factors also depends on the real situation. We suggest that when group judgement is used, whether the suggestion of weighting by 0.1–CR(i) still needs to be discussed further more.

REFERENCE

(1) Kathawala, Y. and Gholamnezhad, H. (1987) "New Approach of Facility Locations Decision", INT. J. SYSTEMS SCI., Vol. 18, No. 2, pp 389–402.

(2) Rohmert, W. (1986) Arbeitswissenschaft I, Darmstadt

(3) Schmidtke, H. (1981) Lehrbuch der Ergonomie, Hanser.

(4) Saaty, T. L. (1980) The Analytic Hierarchy Process, McGraw–Hill, Inc.

(5) Wang, L. F. (1987) "The Calculations of the Ordering Weight in AHP", Theory & Practice of Systems Engineering, No. 2, pp 31–37.

(6) Xu, S. B. (1986) The Principle of Analytic Hierarchy Process, the Institute of Systems Engineering of Tianjing University.

NOTE: This project is supported by Chinese Natural Sciences Foundation and the Stiftung Volkswagenwerk of Fedral Republic of Germany.