The Application of AHP to the Evaluation of General Performance Engineering Machinery

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ABSTRACT

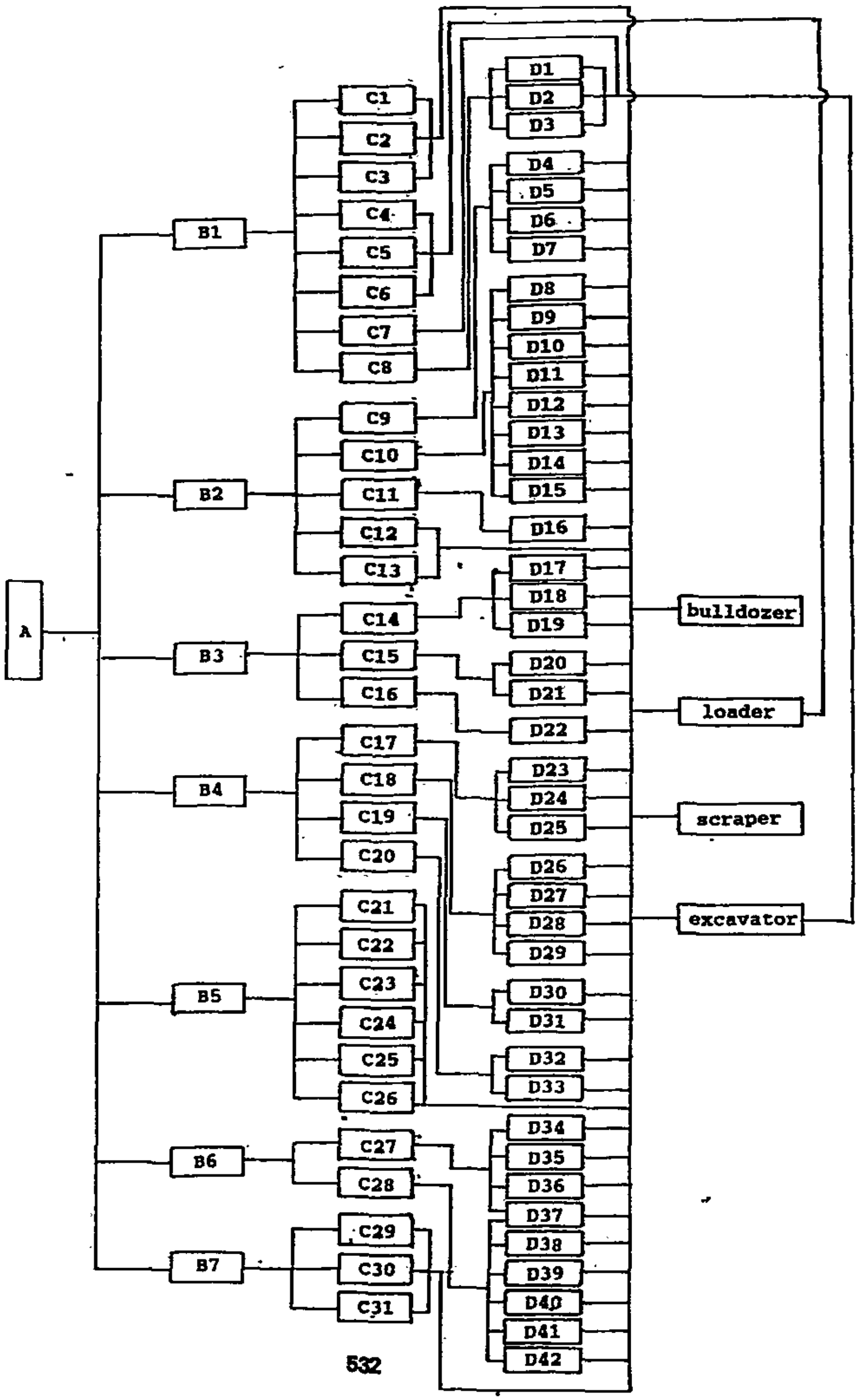
In this paper we provide with a system of evaluated indexes of general machinery performances basing on the AHP. The hierarchy structure of the evaluated indexes system is discribed in detail in the first section. Then we calculated the priorities of the evaluated indexes combined with fuzzy membership and recommanded the indexes to evaluate general machinery performances. In the final section we illustrate some examples as the evaluations of caterpillar and wheeled bulldozers.

I. Introduction

The evaluation of general performance of engineering machinery is both a qualitive and quantitative problem. The AHP can solve such problem effectively by structuring a hierarchy of indexes system and by eliciting judgments to develop priorities of the indexes. It thus combines the index system with practial evaluated problem. In this paper we studied the engineering machinery using the AHP by first defined the situation carefully, including as many relevant details as possible, then structured it into a hierarchy of levels of detail indexes (Figure 1). We then established relationships between the elements of each level of the hierarchy by comparing the elements in pairs and quantitate fuzzy indexes. So that the established index system is of practical value. By doing so we provided a structured hierarcal model, calculated the priorities and applied the concepts of fuzzy membership in the quantitative theory. We also illustrate the practical value of the above method with a real-fife application and the result shows reliablisity.

II. Evaluated System Indexes and Model

We began by laying out the related elements, which attribute to the general performance, of the engineering machinery as a hierarchy. We then made paired comparisons among the elements of a level as required by the criteria of the next higher level. These comparisons gave rise to priorities and finally, through sysnthesis, to arrive the global priorities. The number of elements that is chosen are no more than desired to represent the general performance. We thus gave a hierarchical indexes system of general performence evaluation of bulldozers.


A
B1
B2
B3
B4
B5
B6
B7
C1
C2
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C4
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C9
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D37
D38
D39
D40
D41
D42
bulldozer
loader
scraper
excavator

A	general performance		
B1	operation performance	B2	flexible performance
B3	safety performance	B4	generalized reliability
B5	protection performance	B6	man-machine performance
B7	economic performance		
C1	effective operation ability	C2	operation hitch
C3	rate of shearing force	C4	digging power
C5	height of unloading-loading		
C6	distance of unloading-loading		
C7	rate of efficacy	C8	operation range
C9	power property	C10	passable property
C11	smooth-going property	C12	average velocity
C13	maximum travel	C14	direction steadiness
C15	indination-resistant property	C16	brake property
C17	reliability	C18	maintainable property
C19	durability	C20	effectiveness
C21	discovery defence	C22	hit defence
C23	puncture defence	C24	destroy defence
C25	tri-defence performance	C26	shrapnel defence
C27	operation property	C28	comfortable property
C29	development cost	C30	purchasing cost
C31	cost of guarantee application		
D1	height of operation	D2	radius of operation
D3	depth of operation	D4	maximum road velocity
D5	acceleration time	D6	maximum slope-velocity
D7	maximum degree of climbing a slope		
D8	loose pavement velocity	D9	minimum road clearance
D10	angle of approach	D11	angle of departure
D12	minimum radius of turning		
D13	height of overcoming vertical tower		
D14	average width of horizontal trench		
D15	average angular velocity of changing direction		
D16	allowance velocity of vibration		
D17	adhesive weight of travelling		
D18	rate of the slanting distance and travel		
D19	frequency of operation with definitive travel		
D20	maximux angle of cross wise slope		
D21	turning angle of cross wise slope		
D22	distance of brake	D23	average life-span
D24	unefficient rate	D25	degree of reliability
D26	average time of repair	D27	rate of maintenance
D28	degree of maintenance		
D29	average time of preventing maintenance		
D30	average working time of first hitch		
D31	limit lift-span		
D32	inherent degree of effectiveness		
D33	reachable degree of effectiveness		
D34	portable property	D35	visible property
D36	property of the field of vision		
D37	space property		
D38	average square value of accelation		
D39	voice	D40	aritight property
D41	tempreratuse	D42	exit-entrance

III.Priorities of Varying Indexes

The reasonableness of priorities of indexes is mainly determined by the pairwise comparison matrix against one critrion in a reasonable structural hierarchical evaluated indexes system. To maintain this reasonableness, we must make good use of people's experiences and judgments. So we structured two kinds of comparison matrix. One is basing on the general judgments of decision makers, as in the second level, which requires more consideration on policy but less on specialty. In our application we consulted 47 experts and decision makers of 29 units. The results is of a 86% consistencey in the ranking of indexes. The other is determined through discusions of our research group, and through further consulting the experts, as in the third and fourth level, and thus guaranteed the validity of the comparison matrix. In this way we can maintain reasonableness of the calculated priorities of the indexes. The result of the calculation of indexes indicated such consistency.

The comparison matrices of the above engineering machinery application are omitted here.

IV. Quantitating the Value of Indexes and Linear Weighted and Ideal Point Methods

Because 58 evaluating indexes are different in dimension, functional relations and are of different types, so they are not comparable. We have to quantitating the value of each index in order to synthesize a single goal system, its quality can thus be judged generally. So to evaluate the general performance of engineering machinary using the AHP, we need not only to calculate the priorities of each index but also to quantitatly the differnt values of each index. We use the membership function, also called utility function to mechanical system, to realize this quantitation. It indicates the relation between the contribution of each index to the general performance and the index value.

Suppose the index function of plan j is $e_i = f_i(x)$, $(i=1.2....,m)$

The minimum value is m_i, the maximum is M_i. Generally, the index function set $F_j(x)$ can be divided into three subsets:

$$F_j(x) = \{ f_1(x), f_2(x), ...f_m(x) \} = f_q(x) \cup f_h(x) \cup f_s(x), \quad (j=1,2,...,n)$$

The $f_q(x)$, $(q=1,2,...,G)$ includes those indexes which have the feature of the greater the value the greater the contribution. The subset $f_h(x)$, $(h=G+1,...,H)$ is formed by those indexes with the property of the greater the value the smaller the contribution. The subset $f_s(x)$, $(s=H+1,\dots,m)$ includes middle value of the indexes. Suppose the membership function is linear, we give the membership function of the above three index subsetsa as following: (Figure 2)

Maximum Type: $(i=1,2,\dots,G)$

$$B(e_i) = \frac{e_i - m_i}{M_i - m_i} = \begin{cases} 1 & (e_i \geq M_i) \\ \dfrac{e_i - m_i}{M_i - m_i}, & (m_i < e_i < M_i) \\ 0 & (e_i \leq m_i) \end{cases}$$

Minimum Type: $(i=G+1,\dots,H)$

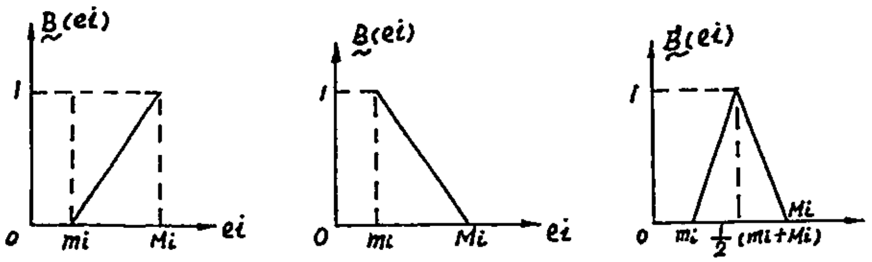
$$B(e_i) = \frac{M_i - e_i}{M_i - m_i} = \begin{cases} 1 & (e_i \leq M_i) \\ \dfrac{M_i - e_i}{M_i - m_i}, & (m_i < e_i < M_i) \\ 0 & (e_i \geq m_i) \end{cases}$$

Middle Type: $(i=H+1,\dots,m)$

$$B(e_i) = \begin{cases} \dfrac{2(e_i - m_i)}{M_i - m_i}, & \left(m_i \leq e_i < \dfrac{M_i - m_i}{2}\right) \\ \dfrac{2(M_i - e_i)}{M_i - m_i}, & \left(\dfrac{M_i - e_i}{2} \leq e_i \leq M_i\right) \\ 0 & (e_i < m_i,\ e_i > M_i) \end{cases}$$

The membership function can be of different shape.

So we can see that to quantitating the evaluating indexes we should give the membership function of each kind of indexes and decide the minimum value m_i and the maximum value M_i.



a Maximum b Minimum c Moderate

Figure 2 The Linear Membership Function

Follow the above process we can compare between the indexes of different dimension and make it a rule for all kinds of indexes that the greater the memebership, the contribution to the general performance.

Basing on the above work, we can build a general performance evaluating function. We recommand "Linear Weighted Sum Function" (LWSF) method and "Ideal Point Function" (IPF) method to evaluate the general performence of engineering machinery.

1.. LWSF

LWSF is given as the following:

$$U_j(x) = \sum_{i=1}^{m} B_{ji} W_{ji}, \quad (j=1,2,\dots,n)$$

$U_j(x)$, B_{ji}, W_{ji} indicate the LWFS, the membership of the ith index and the weight of the ith index f the j plan system. respectivelly.

Thus we transfer the multi-objective decision problem $\text{V-max}_{x \in R} F_i(x)$ into a single-objective maximizing problem $U_j(x)$. We can give global ranking of the plan system according to the value of $U_j(x)$. When the two $U_j(x)$ values are close, we can construct twice evaluating function and evaluate it the second time. Or we can reevaluate it through other evaluating function.

2. IPF

The evaluation function of IPF type is as following:

$$y(x_j) = 1 - \sum_{i=1}^{m} w_{ji} (1-B_{ji})^2, \quad (j=1,2,\dots,n)$$

$y(x_j)$ indicates the membership of plan j to ideal plan ($y(x_0)=1$). We can rank all plan system according to the value of $y(x_j)$.

V. The Application of the Method to General Porformance of Engineering Machinery and Its Results

Using the above evaluating model of general performance of engineering machinery, we evaluated four kinds of bulldozers T74, T85 (wheeled bulldozers), T81, T82 (caterpullar bulldozers).

1. The evaluating results are as follows:

In Table 1 we can see that the results is close to real neasurement value. The error is less than 10%.

In Table 2 we can conclude that most indexes of T82 are better than that of T81.

In Table 3 we find that the reliability and economical indexes of T74 is far better than that of the other three bulldozers.

2. The calculation of subindexes system

We find in Table 4 that calcultions of subindexes system are in consistant with the results of the evaluating index systems above. The calculations also indicate the quality of index and subindex system and thus help in disigning a new plan and improving product.

3. Evaluating results of general performance system

See Table 5.

4. The results of flexibility (Table 6)

The result in Table 6 indicates that the general performance of T85 will be far better than that of T74 provided which provided us to improve the level of reliability of T85 to that of T74.

Table 1 The Comparison of the Calculating Value and the Practical Value

Indices		Models	T 74	T 85	T 81	T 82
C1 (N)	Calculating Values		82790	125572	158802	162128
	Practical Values		83300	141120	151802	155330
D4 (km/h)	Calculating Values		51.21	52.58	42.81	47.40
	Practical Values		52.00	53.00	44.25	47.60

Table 2 The Comparison of the Index Values of T82 and T81 Bulldozers

Models / Indices	T 82	T 81	Models / Indices	T 82	T 81
C1(N)	162128	158802	$C2(m^3/h)$	146	98
C3(N/m)	41442	39210	D4(Km/h)	47	43
D6(Km/h)	35	29	D8(Km/h)	47	46
D9(m)	.415	.400	D10(o)	38	28
D15(1/sec)	.599	.446	D16(Km/h)	47	43
C12(Km/h)	32	29	C13(Km)	204	184
D23(h)	34	21	D24(1/h)	.029	.047
D25(Probability)	.49	.32	D30(h)	77	30
D32(Ratio)	.93	.90	D33(Ratio)	.90	.87
$D38(m/S^2)$	1.093	1.136	C21(Probability)	.0054	.0017
C22(Probability)	.240	.116	C23(Probability)	.0536	.0390
C24(Probability)	.943	.871	C26(Probability)	.741	.625
D35(Ratio)	80	29	C29(10000 Y)	69	101
C30(10000 Y)	22	27	D7(o)	21	36
D11(o)	27	36	D12(m)	4.47	2.42
D26(h)	2.69	2.34	D29(h)	2.75	2.35
D34(Ratio)	.847	.525	D37(m)	2.56	2.64
D39(dB)	101	97	C31(Y/Workshop)	513	440

Table 3 The Comparison of T74 and the Bulldozers of Other Three Kinds

Models / Indices	T 74	T 85	T 81	T 82
C1(N)	82790	125572	158802	162128
$C2(m^3/h)$	38	71	98	146
C3(N/m)	25953	38052	39210	41442
D16(Km/h)	25	33	43	47
D23(h)	80	14	21	34
D30(h)	102	18	30	77
C29(10000 Y)	57	84	101	69
C30(10000 Y)	16	30	27	22
C31(Y/Workshop)	128	267	440	513

Table 4 The Evaluating Results of Every Sub-system

Sub-systems	Plans	74 Style	85 Style	81 Style	82 Style
Operation Performance	Calculating Values	.030	.103	.164	.239
	Optimal Consequence	4	3	2	1
Flexible Performance	Calculating Values	.036	.044	.073	.077
	Optimal Consequence	4	3	2	1
Safety Performance	Calculating Values	.049	.062	.083	.077
	Optimal Consequence	4	3	2	1
Reliability	Calculating Values	.158	.030	.062	.094
	Optimal Consequence	1	4	3	2
Protection Performance	Calculating Values	.010	.005	.018	.027
	Optimal Consequence	3	4	2	1
Man-machine Performance	Calculating Values	.042	.059	.062	.051
	Optimal Consequence	4	2	1	3
Economic Performance	Calculating Values	.083	.043	.021	.020
	Optimal Consequence	1	2	3	4

Table 5 The Calculating Results of Three Different Kinds of Methods

Models / Methods	T_{74}	T_{85}	T_{81}	T_{82}	Types of Values
Linear Weighted Sum Method	.584	.483	.407	.346	the bigger, the better.
Ideal Point Method	.504	.413	.309	.295	the bigger, the better.
Suppositional Object Method	.437	.518	.587	.619	the smaller the better.

Table 6 The Calculating Results of Sensitivity by Means of the Linear Weighted Sum Method

Models	T74	T85	T81	T82
Calculating Values	.407	.476	.483	.584
Optimal Consequence	4	3	2	1

VI. Conclusions

By using the evaluating model of the general performance system. it has been proved that the calculated values of the evaluated indices, the evaluated results of the sub-performance system. that of the general performance system and that of sensitivity all accord with the actual situation, and the quantitative analysis coincides perfectly with the qualitative analysis.The quantitative analytic results of the model shows us not only the priorities of the sub-system performance and the gereral performance, but also the reasons for priorities.It points out the direction for the improvement and decision of the plan system, and provides quantitative basis. The model is able to choose evaluated indices and system evaluating method flexibly, and able to have sensitivity analysis. It has great flexibility and strong suitability. The model is able to evaluate not only the wheeled and caterpillar engineer machinery but also the wheeled amd caterpillar vehicles. This evaluating method is common to other specialized subjects and multiobjective decision making. So it has wide common use. It is a new and effective means of system proof and decision making scientifically.

References

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