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Research on model-based rubber formula decision

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ABSTRACT

In order to cope with ambiguity and uncertainty in rubber formula decision, the author, by making use of 13 groups of rubber formula test data, firstly establishes a multivariant linear regression model involving relations of raw materials and their performances; and further establishes a multi-objective programming model of priority level by taking into consideration the regression coefficients obtained from the former model and the target constraint requirements, and then employs appropriate weights to this multi-objective programming model. This research on rubber formula decision reveals the feasibility and validity of the multivariant linear regression model and the multi-objective programming model.

KEYWORDS

Rubber formula; Multivariant linear regression model.

INTRODUCTION

If a rubber product comprising three raw materials of certain proportion be tested, 9 performance parameters will be obtained. When asked to meet some constraint requirements to these 9 parameters for special rubber products by consumers, a manufacturer with no clear idea of the intrinsic relations of raw materials and their performances usually tries desperately to find out the right formula by testing again and again---that is a serious waste of manpower, materials, money and time[1]. In order to solve this problem, we plan to conduct a research on model-based rubber formula decision. With such known conditions as plenty of test data on Raw Materials and Nine Performance Parameters and constraint requirements to these 9 parameters, we have to identify the problem first and then find out the right way to solve this problem: determine the relations of the three raw materials and their nine performance parameters and design certain targets for mathematical operation; find out the intrinsic relations of the experimental data on raw materials and 9 performance parameters through the multivariant linear regression model, and achieve the final solution through the multi-objective programming model of priority level.

DATA SOURCES AND REQUREMINTS

TABLE 1 is about 13 groups of the test data on 3 raw materials of certain mixing proportion and their 9 performance parameters[1]. TABLE 2 is about the constraint requirements on the raw materials and their performance parameters.

TABLE 1 : 13 groups of the test data

	A	B	C	D	E	F	G	H	I	J	K	L
1	PP1	PP2	PP3	PP4	PP5	PP6	PP7	PP8	PP9	RM1	RM2	RM3
2	124	543	18	49	1.02	62	32.2	−1.4	40	50	10	0.55
3	150	500	16	72	0.9	84	31.1	−1.5	41	90	10	0.55
4	123	563	21	50	1.05	80	33.4	−1.3	46	50	25	0.55
5	160	526	17	70	1.01	78	32.2	−1.1	45	90	25	0.55
6	170	351	4	54	0.91	63	18.1	−3.9	41	50	10	1.95
7	192	300	4	80	0.91	82	17.2	−4	40	90	10	1.95
8	162	372	5	50	0.9	84	19	−3.6	45	50	25	1.95
9	186	336	4	7	0.89	78	17.3	−3.8	44	90	25	1.95
10	140	760	7.6	49	0.8	43	28.4	−1	45	36.3	17.5	1.25
11	160	200	6	88	0.807	114	19.2	−4.2	40	103.6	17.5	1.25
12	107	662	32	52	1.16	76	52	−4.2	42	70	17.5	0.07
13	225	306	2	72	0.67	77	15.3	−6	40	70	17.5	2.42
14	206	375	8	68	0.86	78	23.2	−3.6	41	70	17.5	1.25

TABLE 2 : Parameters with some constraint requirements

Factors	Constraint symbol	Constraint value	Level of priority	Level of weight
RM1	<	90	1	8
RM2	<	25	1	8
RM3	<	2	1	8
PP1	>	83	3	1
PP2	>	-470	3	1
PP3	>	21	2	3
PP4	>	31	3	1
PP5	<	-0.2	1	8
PP6	>	40	3	1
PP7	<	-25	1	8
PP8	<	-2	3	1
PP9	>	-0.47	2	3

MULTIVARIANT lINEAR REGRESSION MODEL AND MODEL MATHEMATICAL OPERATION

Multivariant linear regression analysis is the regression analysis of the relations of one dependent variable and many independent variables. Based on the actual observed values of the dependent variable and the independent variables, we may establish the multivariant linear regression equation of the independent variables and the dependent variable[2,3].

(1)Suppose the variable y and independent variables x_1, x_2, …, x_m produce n groups of actual observed data:

TABLE 3 : *n* groups of test data

Variable numbwr	y	x_1	x_2	…	x_m
1	y_1	x_{11}	x_{21}	…	x_{m1}
2	y_2	x_{12}	x_{22}	…	x_{m2}
⋮	⋮	⋮	⋮	…	⋮
n	y_n	x_{1n}	x_{2n}	…	x_{mn}

Given that the dependent variable y and the independent variables x_1, x_2, …, x_m are of linear dependence. Their mathematical model is:

$$y_j = \beta_0 + \beta_1 x_{1j} + \beta_2 x_{2j} + \ldots + \beta_m x_{mj} + \varepsilon_j \quad (j=1,2,\ldots,n) \tag{1}$$

(2) Suppose the m variants linear regression equation of y and x_1, x_2, …, x_m is:

$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_m x_m$, in which b_0, b_1, b_2, …, b_m are the minimum squares estimated values of β_0、β_1、β_2…、β_m, i.e. b_0, b_1, b_2, …, b_m enable the sum of squared deviations of the actual observed value y and the estimated value $\hat{y}$ be the minimum.

(3)Calculate b_0, b_1, b_2, …, b_m, and then obtain the linear regression equation.

Take example by "RM- PP 5" in the 13 groups of data, its multivariant linear regression evaluation in Excel is shown in Figure 1:

SUMMARY OUTPUT

Regression satistics	
Multiple R	0.757916345
R Square	0.574437186
Adjusted R	0.432582914
Std.deviation	0.094123474
Value	13

Analysis of variance

	df	SS	MS	F	nificance F
Analysis	3	0.107626	0.035875	4.04949	0.044635
Residual	9	0.0797331	0.008859		
Total	12	0.1873591			

	Coefficient	Std.deviation	Stat	P-value	Lower 95%	Upper 95%
Intercept	1.078768341	0.1293138	8.342255	1.6E-05	0.78624	1.371296
RM1	-0.00057705	0.0012733	-0.45321	0.66113	-0.00346	0.002303
RM2	0.001833333	0.004437	0.41319	0.68914	-0.0082	0.011871
RM3	-0.12493933	0.0364139	-3.43108	0.0075	-0.20731	-0.04257

Figure 1 : Excel regression statistics of PP5 and raw materials

In Figure 1, “Adjusted R=0.432582” means that three independent variables can explain 43% of performance change of PP5, indicating that the fitting effect of regression equation is not outstanding. In the Analysis of Variance of Figure 1, the P value in correspondence with statistical magnitude F is 0.00446, indicating that regression equation is significant. In the Coefficients of TABLE 2, we can get the constant term (Intercept), as well as the estimated coefficients of raw material 1, raw material 2 and raw material 3. Consequently, the multivariant linear regression equation of PP5 and raw materials is:

$$y_5 = 1.0787 - 0.000577 x_1 + 0.00183 x_2 - 0.12493 x_3 \tag{2}$$

Likewise, we can obtain the linear regression equations of the other eight performance parameters in relation to raw materials.

ESTABLISHMENT OF GOAL PROGRAMMING MODEL OF PRIORITY LEVEL AND EVALUATION

Simon, from Carnegie-Mellon University in the United States, holds that "a satisfactory behavior model is much richer than a maximum behavior model"[4]. In modern enterprise management, the optimum as to policy decisions is only relative. As to a typical policy decision made under given conditions of limited resources, the order or priority of objectives to realize is stated, and the program with minimum deviation of all objectives integrated together is preferred. Goal programming which is to optimize all planned objectives is only partially satisfactory, as only the objectives of higher priority level are satisfied and those of lower priority level are not. Therefore, when searching solutions based on model, policy makers prefer to endow different objectives and constraints with different weights.

Nine equations of raw materials and performance parameters are obtained. To meet the constraint requirements in paper, we set to establish the constraint equation.

Determine the decision variables

Suppose that x1,x2,x3 represent the recipe amount of three raw materials respectively and the goal consists of 5 primary targets, 2 secondary targets and 5 tertiary targets, corresponding to 12 pairs of deviation variables $d_i^+, d_i^- \quad (i = 1, \ldots, 13)$.

Determine the target function

Preset corresponding weights for the targets of different levels: 8 for the primary, 3 for the secondary and 1 for the tertiary. Sum all the weighted deviations as the target function, and find the minimum value. Thus, the target function is:

$$\min f = (8d_1^+ + 8d_2^+ + 8d_3^+ + 8d_4^+ + 8d_5^+ + 3d_6^- + 3d_7^- + d_8^- + d_9^- + d_{10}^- + d_{11}^- + d_{12}^-)$$

Determine constraint conditions

5 primary targets:

$$\begin{aligned}
&x_1 + d_1^+ - d_1^+ = 90\\
&x_2 + d_2^+ - d_2^+ = 25\\
&x_3 + d_3^+ - d_3^+ = 2\\
&-0.00058x_1 + 0.001833x_2 + -0.12494x_3 + +d_4^+ - d_4^- = -0.23357\\
&-0.07454x_1 + 0.055x_2 - 12.4777x_3 + +d_5^+ - d_5^- = -25.482
\end{aligned} \tag{3}$$

2 secondary targets:

$$\begin{aligned}
&-0.03539x_1 + 0.083333x_2 - 11.0471x_3 + +d_6^+ - d_6^- = 21.576\\
&-0.03811x_1 + 0.3x_2 - 0.55931x_3 + d_7^+ - d_7^- = -0.47
\end{aligned} \tag{4}$$

5 tertiary targets:

$$\begin{aligned}
&0.524761x_1 - 0.08333x_2 + 36.86403x_3 + d_8^+ - d_8^- = 83.428\\
&-4.06018x_1 + 1.716667x_2 - 143.652x_3 + d_9^+ - d_9^- = -470.867\\
&0.335127x_1 - 1.3x_2 - 1.7264x_3 + d_{10}^+ - d_{10}^- = 31.093\\
&0.557947x_1 + 0.483333x_2 + 0.490699x_3 + d_{11}^+ - d_{11}^- = 40.754\\
&-0.02044x_1 + 0.016667x_2 - 1.36118x_3 + d_{12}^+ - d_{12}^- = -2.138
\end{aligned} \tag{5}$$

With weighted priority, this will change into a common linear programming issue for one single target. To this problem, the satisfactory solution is:

$$\begin{aligned}
&x_1 = 58.5, x_2 = 9.1, x_3 = 1.7,\\
&d_1^+ = 0, d_1^- = 31.5, d_2^+ = 0, d_2^- = 15.9,\\
&d_3^+ = 0, d_3^- = 0.27, d_4^+ = 0, d_4^- = 0.06,\\
&d_5^+ = 0, d_5^- = 0, d_6^+ = 0, d_6^- = 42,\\
&d_7^+ = 0, d_7^- = 0, d_8^+ = 10.39, d_8^- = 0,\\
&d_9^+ = 0, d_9^- = 0, d_{10}^+ = 0, d_{10}^- = 26.3,\\
&d_{11}^+ = 0, d_{11}^- = 2.85, d_{12}^+ = 0, d_{12}^- = 1.26
\end{aligned}$$

the optimum value is: $f = 155.3$

CONCLUSIONS

On the basis of 13 groups of experimental data on certain rubber product, we establish successively the multivariant linear regression model and the goal programming model to the research on rubber formula decision. We find that these two models, practical and easy to understand, can simplify the process of rubber formula decision, and the evaluation in turn shows the feasibility and effectiveness of these two models.

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