A modelling study on multi-mine and multi-product in Guizhou province, China

Using dynamic planning method to construct the model for multi-mine and multi-product, this research tries to establish a new normal bauxite mine industry and upgrade the scientific production decision of bauxite industry. The optimal results, based on 6 bauxite deposits, show that after optimization, the inventory costs of 6 bauxite mines in 2016 have been reduced. Meanwhile, the optimal production decision suggests that, in the current new normal, bauxite enterprises should realize that this decision of expanding individual mine production to reduce the unit cost of bauxite may be unable to get the maximum profit as a whole.

Keywords: *Model; optimal product portfolio; bauxite; dispersant.*

1. Introduction

Currently, China's economic development has shown a new normal transformation from high-speed growth into medium-and-high growth. Such irreversibly trendy development status has motivated China's bauxite mine industry to enter into the new situation featuring the "coexistence of four phases": slackened demand growth, intensified environmental constraint, look-ahead productivity construction, high inventory operation and industry structural adjustment. The falling bauxite price has made the entire industry face with the situation of overall loss, and the bauxite mine industry has also entered into the new normal. Moreover, bauxite [l] mine enterprises, large-scale bauxite mine groups in particular, have been compelled to consider the applicability of extensive production decision pattern of chasing profits at the expense of resource overdraft; meanwhile, they will realize that it is of great importance to adjust the decisions of production and inventory costs effectively, under the complex and volatile external environment, in order to realize profit maximization.

On this basis, this article takes multiple mines affiliated to large-scale bauxite mine groups as the research objects; constructs a production decision model and puts cost minimization as the objective function, aiming at realizing the optimal product mix of multi-bauxite [l] and multi-product and the overall profit maximization. In the end, this article conducts an empirical analysis on the research objects to verify the applicability and reliability of this model; provides the theoretical and realistic basis for bauxite mine enterprises to enhance the scientific and efficient production decision.

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2. Production decision model

2.1 Model assumption

Scholars at home and abroad have conducted in-depth researches on production decision model and adopted various theories and methods for model construction, such as mathematical programming theory, fuzzy random theory and game theory; and, a lot of researches are about production decision of bauxite mine enterprises in China. Douglas production function was used to analyze a certain bauxite mine group; a multi-objective programming model based on productivity, demand, inventory and other constraints, was constructed to confirm the production plan of bauxite enterprises but ignoring the operation cost of enterprises; for bauxite mine enterprises adopting MTO business policy, the production decision optimization model was constructed for minimum cost and the conditions for optimal solution .

On the other hand, in above researches, the dynamic programming method is a widely used method generally and its innovation lies in the state transition equation design and the optimization algorithm development. In this article, the decision model is used to optimize the monthly production and inventory cost with 16 matrix variables and get the optimized situation for 12 months, so the algorithm used in dynamic programming model is more likely to be realized compared to fuzzy random theory and game theory.

For the scientificity and logicality of the research, this article proposes the presumptions and hypotheses for the production decision model based on previous research results as follows: (1) it is assumed that all of bauxite mines are under the stable development situation during the period of decision making, aiming for minimum gross production and inventory cost of multiple bauxite mines; (2) it is assumed that the bauxite mine market features perfect competition; the production change of individual bauxite mine will never influence on the overall demand and supply of the market; (3) it is assumed that the supply and demand of various bauxite mines share the same direction with bauxite mine market, regardless of the lag reactive based on the rational assumption, namely when the bauxite mine market features over supply, the overall inventories of commercial bauxites in multi-mine will not be equal to 0; (4) it is assumed that all of raw materials needed in production process feature the stable market prices.

2.2 Model construction

$$\min C = \sum_{t=1}^{T}\sum_{n=1}^{N}\left[C_n\left(A_{nt}\right) + f_n\left(\lambda_{nt} * A_{nt}\right) + \sum_{i=1}^{2} g_{in}\left(\sum_{m=1}^{M} Q_{nimt}\right)\right] + \sum_{t=1}^{T} h\left(\sum_{m=0}^{M} v_{mt}\right) + C_{0t}$$

$$S.t\begin{cases} v_{mo} = 0, v_{m12} = 0, 0 \le \sum_{m=1}^{M} v_{mt} \le v_{\max t} \\ d_{mt} = \sum_{n=1}^{N}\sum_{i=1}^{2} Q_{nimt}, 0 \le \sum_{m=1}^{M} Q_{nmit} \le Z_{nit} \\ 0 \le \lambda_{nt} * A_{nt} \le \min\left(\lambda_{nt} * X_{nt}, Y_{nt}\right) \\ x_{mt} = \sum_{n=1}^{N} A_{nt} * \left[\left(E_{nt} - \lambda_{nt}\right) * \sigma_{nmt} + \lambda_{nt} * \lambda_{nmt}\right] \\ v_{mt} = v_{m(t-1)} + x_{mt} - d_{mt} \Rightarrow v_{mt} = \\ \sum_{k=1}^{t}\left(x_{mk} - d_{mk}\right) \le \sum_{j=t+1}^{T} d_{mj} \end{cases} \quad \ldots \quad (1)$$

Generally speaking, the bauxite mine production system decision point is quantity-cost-profit of multi-mine and the optimal product portfolio. In this article, the objective function and constraint conditions of the variables involved have a complex relationship.

According to the model assumptions and the variables' definition, the main constraint conditions are: (1) a complete production cycle without stock at the beginning and the end; (2) all bauxite mines should ensure the supply in each period of time so that there is no shortage of phenomenon; (3) the output of each stage should be less than the capacity; (4) at the end of each period, the bauxite inventory is no greater than the sum of the demand in the future. Finally, the optimal production portfolio decision model for multi-mine and multi-product based on cost minimization is above.Where, n indicates the n^{tn} bauxite mine; i indicates the mode of transportation (i=1 indicates rail transportation; i=2 indicates road transportation); m indicates the m^{tn} commercial bauxite; t indicates the t^{tn} decision-making phase; this article selects one year as the entire decision-making period, which is divided into 12 decision-making phases by months, namely t=1,2,...12.

A_{nt}: indicates the production of raw bauxite produced by bauxite mine n during period t; X_{nt}, Y_{nt}, Z_{nit} and V_{maxt} indicate the production capacity, washing and cleaning capacity, transportation capacity and overall inventory capacity of bauxite mine n during period t respectively; λ_{nt} and λ_{nmt} indicate the rate of raw bauxite for washing of bauxite mine n during period t and the washing rate of commercial bauxite m; σ_{nmf} indicates a model correction parameter with the matrix structure, in which the values are set to 1 if bauxite mine n has the unwashed bauxite m and the other values are set to 0.

V_{mt} indicates the inventory of commercial bauxite n at the end of period t and assumed V_{mo}=0, V_{m12}=0; d_{mt} indicates the demand of various types of bauxites, which is assumed to be known in this article; x_{mt} indicates the overall volume of commercial bauxites summarized by various bauxite mines (including direct-selling bauxite and cleaned bauxite); Q_{nimt} indicates the sales volume of commercial bauxite m selected by bauxite preparation plant n for customer i (two modes of transportations are virtualized into two customers) during period t; C_{0t} indicates the other fixed cost of bauxite mine n.

Meanwhile, $C_n(A_{nt})$, $f_n(\lambda_{nt}*A_{nt})$, $g_{in}(Q_{nimt})$ and $h(V_{mt})$ indicate the dynamic cost functions and inventory cost functions during raw bauxite mining period, washing and cleaning period, transportation and marketing period which are calculated based on history data and actual production and sales volume.

Due to the adoption of subsequent statistical analysis on the dynamic cost data of bauxite mining preparation in most of bauxite mines, the assumed linear relation between dynamic cost and productivity does not accord with the actual and typical phenomenon that bauxite mine enterprises still expand their production and intend to get a reduction of per tonne bauxite cost even if the price is declining. Meanwhile, there can be negative linear relationship between cost and output, therefore it is assumed that there is a non-linear function relation between them; and this decision model is used to judge the rationality of bauxite mine enterprises' measures under the optimal production decision.

Based on the model assumptions mentioned above, this article refers to the definition of value range of inventory; deduces the specific calculation function of inventory from the function of X_{mt} in eq.1 and mtv has a maximum value equalling to $\sum_{k=1}^{t}\left(x'_{mt} - d_{mk}\right)$ where $x'_{mt} = x_{mt}\left(X_{nt}\right)$ if the production equals to the capacity in every month; deduces the maximum value of X_{mt} from the function of $v_{mt} = \sum_{k=1}^{t}\left(x_{mk} - d_{mk}\right)$ in eq.1 and X_{mt}. Above all, the optimized model is as follows:

$$
S.t\begin{cases}
v_{mo}=0, v_{m12}=0, 0\le\sum_{m=1}^{M}v_{mt}\le v_{\max t}\\
d_{mt}=\sum_{n=1}^{N}\sum_{i=1}^{2}Q_{nimt}, 0\le\sum_{m=1}^{M}Q_{nmit}\le Z_{nit}\\
0\le\lambda_{nt}*A_{nt}\le\min(\lambda_{nt}*X_{nt},Y_{nt})\\
x_{mt}=\sum_{n=1}^{N}A_{nt}*[(E_{nt}-\lambda_{nt})*\sigma_{nmt}+\lambda_{nt}*\lambda_{nmt}]\\
v_{mt}=\sum_{k=1}^{t}(x_{mk}-d_{mk})\Rightarrow\sum_{i=1}^{t}\sum_{n=1}^{N}\{A_{nt}*(E_{nt}-\lambda_{nt})\\
\sigma_{nmt}+\lambda_{nt}\lambda_{nmt}]-Q_{nimt}\}\\
A_{nt}*[\sigma_{nmt}(1-\lambda_{nt})+\lambda_{nt}*\lambda_{nmt}]-Q_{nimt}\ge 0\\
0\le v_{mt}\le\min\left(\sum_{k=1}^{t}(x'_{mt}-d_{mk}),\sum_{j=t+1}^{T}d_{mj}\right)\\
0\le x_{mt}\le\min(v_{mt}+d_{mt},x'_{mt}), x'_{mt}=x_{mt}(X_{nt})
\end{cases}
$$

Apparently, the model mentioned above can be treated as the decision making during period *t*; dynamic programming method can be adopted for model construction of optimal solution where, A_{nt} and Q_{nimt} indicate the decision variables; V_{mt} indicates the state variable; $V_{mt} = V_{mt-1}+X_{md}-d_{mt}$ is the state transition equation. When optimal values function $Y_t(V_{mt})$ is used to indicate the minimum overall cost from period 1 with a primary inventory as 0 to the end of period *t* with a inventory as V_{mt}, then the state transition equation and boundary of the model mentioned above are as follows:

$$
\begin{cases}
y_t(v_{mt})=\min\left[\sum_{n=1}^{N}\left[C_n+f_n+\sum_{i=1}^{2}g_{in}\right]+\right.\\
\left.h\left(\sum_{m=0}^{M}v_{mt}\right)+y_{t-1}(v_{t-1})\right]\\
y_0(v_{m0})=0, 0\le\sum_{m=1}^{M}Q_{nmit}\le Z_{nit}\\
0\le A_{nt}\le\min(X_{nt},Y_{nt}/\lambda_{nt})\\
0\le x_{mt}\le\min(v_{mt}+d_{mt},x'_{mt})
\end{cases}\quad\ldots\quad(3)
$$

Optimal solution of V_{mr} in $y_t(V_{mt})$ during each period within the data range is calculated as the minimum cost $y_{12}(V_{m12} = 0)$. Maximum profit "I" under minimum cost is further obtained.

3. Sampling and analysis

3.1 Data source

In this study selects 6 bauxite mines are selected to get the optimal production decision of product portfolio under minimum cost.This paper sets the year of 2016 as the decision-making period, with each month as a decision phase. Basic data of variables come from the production reports, profit and production plans of the selected bauxite mines. Actual production decisions are shown in Tables 1-3.

Among them, the production of bauxite mines of n=1 and n=2 is more than 10 million tonnes; m=1 indicates the direct marketing commercial bauxite of 4500 kilocalorie; m=2 indicates the direct marketing commercial bauxite of 5000 kilocalorie; m=3 indicates the direct marketing commercial bauxite of 5500 kilocalorie; m=4 indicates the direct marketing commercial bauxite of 5500 kilocalorie, similarly hereinafter.

3.2 Results and discussion

3.2.1 Cost function measurement

In order to eliminate the influence of heteroscedasticity relationship and data unit among various variables in cost function, this article takes the logarithms of all of variables in the function for unitization and standardization processing. Based on the cost and financial reports of mines affiliated between 2015 and 2016, the calculated results show that in addition to the non-linear relationship between raw bauxite mining dynamic cost and production of bauxite mine n=1, there are linear relationships between dynamic cost and production in the remaining bauxite mines, this article focuses on explaining the dynamic cost function of raw bauxite mining n = 1 (eq. 3):

$$\ln C_{1t}=0.79^*(\ln A_{1t})\wedge 2-7.9^*\ln A_{1t}+28.4\left(R^2=0.865\right)\quad\ldots(4)$$

3.2.2 Optimal solution

By combining the solution of general dynamic programming model, this article sets the demands of various types of bauxite in 2016 as the known conditions, and adopts MATLAB7.0 programming to calculate the monthly optimal productivities and optimal product portfolio decisions of 6 bauxite mines of Datong bauxite mine group, under the premise of certain demand of commercial bauxite. Due to limited space, main application of genetic algorithm used in this article will be provided in private; and the results are shown with n=1, n=2, n=3 and n=4 have shown that the optimized productivities of various bauxite mines are lower than the actual productivities, due to that the large inventories of bauxite mines have led to higher inventory costs. Thus, effectively optimized inventory can upgrade the overall profit remarkably. Meanwhile, Eq. 3 has shown that there is a non-linear relationship between dynamic cost and production of raw bauxite mining in bauxite mine n=1, and a inflexion point of the production is 0.28 million tonnes, which indicates a scale effect between the dynamic cost and production of raw bauxite mine. In addition, the optimal production decision of bauxite mine m=3 is the maximum production capacity. This is because that cleaned bauxite of 5500 kilocalorie is produced in bauxite mines n=1, n=2 and n=3 and the lower per tonne bauxite cost in bauxite mine n=3. Consequently, bauxite mine n=3 is put priority to satisfy the demand of this type of commercial bauxites for optimized product portfolio structure.

Table 1: Raw bauxite production, commercial bauxite production and inventory of 6 bauxite mines in 2016 (Unit: 10,000 tonnes)

Data	Production ant						Demand of commercial bauxite dmt				Inventory vmt			
	n=1	n=2	n=3	n=4	n=5	n=6	m=1	m=2	m=3	m=4	m=1	m=2	m=3	m=4
Jan.	4	2	4	8	1	3	4	4	7	42	18	7	14	63
Feb.	8	1	1	2	2	3	9	4	6	43	9	7	14	57
Mar.	7	0	5	0	3	4	3	5	8	73	18	7	14	42
Apr.	7	9	8	0	2	5	3	4	6	74	29	6	14	35
May.	5	8	5	9	7	5	5	6	5	88	27	8	15	33
Jun.	6	7	8	9	5	9	1	4	6	71	34	6	14	35
Jul.	6	2	2	4	3	5	5	5	2	90	12	7	14	29
Aug.	3	2	3	5	3	8	3	5	3	79	21	6	12	28
Sep.	6	6	2	5	5	5	3	9	2	74	17	6	12	26
Oct.	3	9	7	9	1	8	5	5	7	88	21	8	6	21
Nov.	6	9	5	4	6	2	1	8	5	90	26	12	6	56
Dec.	1	4	6	3	8	8	6	8	6	85	27	9	9	51

Table 2: Cost of bauxite mining preparation of 6 mines in 2016 (Unit: RMB 10000)

Data	Cost of bauxite mining preparation						Cost of cleaning			Cost of inventory
	n=1	n=2	n=3	n=4	n=5	n=6	n=1	n=2	n=3	
Jan.	2989.9	3097	3841	2403	4098	4184	3917	3031	4341	21877
Feb.	2818.2	3998	2633	2971	3329	4201	3560	2707	4191	24018
Mar.	4051	3501	3145	2675	3298	4411	4683	4284	3923	24975
Apr.	3843	4284	4509	3627	3818	2244	2957	2873	3815	23362
May.	2231	4334	3605	3797	3593	4539	4606	3480	3748	22920
Jun.	2570	3840	3406	3168	2395	3929	3135	3549	4695	25597
Jul.	4143	4577	4465	4369	3962	3653	2226	3247	2970	122345
Aug.	4295	2534	2924	2549	3003	3417	2987	3274	4182	198872
Sep.	2657	2779	2616	3248	4478	4003	4241	3741	2270	167000
Oct.	3205	4533	2502	2600	2257	3038	2780	4208	3185	177778
Nov.	2249	4480	3152	3349	3982	4015	4270	3065	2834	233366
Dec.	2847	2751	2271	3480	4618	4223	3031	4384	4138	243336

Table 3: Cost of transportation and marketing and fixed in 2016 (Unit: RMB 10, 000)

Data	Cost of transportation and marketing (i=1)						Cost of transportation and marketing (i=2)				Other fixed cost
	n=1	n=2	n=3	n=4	n=5	n=6	n=3	n=4	n=5	n=6	
Jan.	26094	9962	19654	18813	6948	3422	1130	883	419	421	6152
Feb.	23541	12365	9630	8789	9351	5825	1103	1105	489	365	4862
Mar.	22961	21458	7695	6854	18444	14918	425	203	52	82	5211
Apr.	25147	10235	6254	5413	7221	3695	1222	1140	562	546	7451
May.	27654	21523	10860	10019	18509	14983	896	713	412	416	6215
Jun.	29554	10224	9654	8813	7210	3684	1652	1369	821	803	5234
Jul.	25189	11230	9452	8611	8216	4690	1123	1130	855	588	7200
Aug.	26348	15486	8993	8152	12472	8946	1536	1025	32	468	6587
Sep.	30821	17899	6452	5611	14885	11359	125	95	200	62	6094
Oct.	15362	11236	5987	5146	8222	4696	454	463	122	221	7412
Nov.	15482	11578	5233	4392	8564	5038	1276	1350	466	487	7055
Dec.	17792	11968	11589	10748	8954	5428	3458	2452	1447	1536	6785

①*Actual Productivity*

n=1	n=2	n=3	n=4	n=5	n=6
124	102	54	38	21	21
118	101	40	32	20	21
137	99	53	50	21	22
137	109	55	50	21	23
145	128	68	39	20	23
140	107	55	39	20	21
136	102	58	42	19	21
143	102	62	41	19	22
136	102	52	41	19	22
123	111	50	41	19	21
210	124	50	43	18	20
211	99	53	39	18	21

②*Optimized Productivity*

n=1	n=2	n=3	n=4	n=5	n=6
95	91	55	29	7	14
106	87	40	29	7	15
98	93	55	31	7	14
92	98	55	32	8	15
99	82	65	28	8	16
93	92	55	26	7	16
107	98	60	28	7	15
100	76	65	28	8	14
104	110	55	28	7	14
106	79	50	24	8	11
85	95	50	24	7	10
79	118	50	23	8	12

m=3 and m=4 have shown that the inventories of 3 types of commercial bauxites, m=1, m=2 and m=3, have been significantly reduced after optimization, with zero inventory for several consecutive years and the maximum inventory less than 150 kilo tonne. The optimized inventory of commercial bauxite m=4 has been changing continuously with an increment compared to actual value of which the cost of production is the lowest compared to other commercial bauxites; however, the inventory is digested at the end of the year. Generally speaking, the actual monthly average inventory is 800 kilo tonne; and the optimized monthly average inventory is 560 kilo tonne, reduced by 30%.

③*Actual Inventory*

m=1	m=2	m=3	m=4
18	7	14	63
9	7	14	57
18	7	13	42
29	8	14	35
27	6	15	33
33	7	14	35
12	6	14	27
21	6	13	26
17	8	12	26
20	11	10	21
26	8	6	68
27	9	6	51

④*Optimized Inventory*

m=1	m=2	m=3	m=4
3	0	0	36
7	1	0	74
0	0	0	85
0	0	1	83
5	0	4	56
14	2	6	51
5	2	8	55
3	0	10	38
0	0	10	50
1	2	9	38
1	0	5	9
0	0	0	0

Fig.1 shows that the actual total profit of 2016 is RMB 2.486 billion; and the total profit after optimization is RMB 3.466 billion; annual profit is increased by RMB 980 million, increased by 39%, and the optimized inventory cost is reduced by RMB 660 million, with a contribution to the profit growth of 68%. Other profit as RMB 320 million comes from

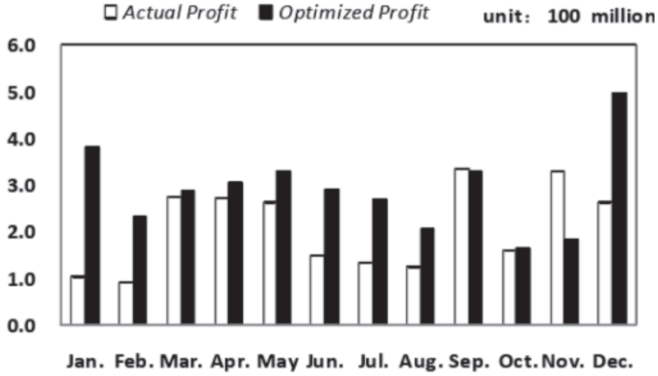

Fig.1 Overall profit of the six mines compared to before and after optimization in 2016

the reduced cost resulted from reduced production in production link.

n=5 and n=6 have shown that the reduced monthly profits in bauxite mine n=1 and n=2 have been transferred to other bauxite mines in view of perspective of profit balance; the severe losses of 3 bauxite mines have been improved significantly, which further realizes the minimum overall cost and maximum profit of multiple bauxite mines.

⑤*Actual Profit*

n=1	n=2	n=3	n=4	n=5	n=6
0.1	2.1	0.3	-0.8	-0.2	-0.5
0.1	2.1	0.0	-0.6	-0.2	-0.5
1.5	1.7	1.1	-0.1	-0.9	-0.4
1.4	2.3	1.0	-0.6	-0.8	-0.5
1.7	2.0	1.3	-0.8	-0.9	-0.6
0.6	2.4	0.8	-0.8	-0.9	-0.6
1.7	1.6	0.6	-0.7	-1.0	-0.8
1.5	1.2	0.7	-0.6	-0.9	-0.7
1.9	2.6	0.8	-0.6	-0.9	-0.5
0.8	1.9	0.9	-0.4	-0.9	-0.7
0.9	3.2	1.0	-0.4	-0.8	-0.6
2.0	3.0	0.4	-1.0	-1.0	-0.8

⑥*Optimized Profit*

n=1	n=2	n=3	n=4	n=5	n=6
1.1	1.5	1.3	0.1	-0.3	0.1
0.8	1.4	0.4	0.1	-0.3	0.1
0.8	1.8	0.9	-0.1	-0.5	0.0
0.9	2.0	0.8	-0.1	-0.5	-0.1
1.3	1.1	1.4	-0.1	-0.4	0.0
0.9	1.6	0.9	-0.1	-0.4	0.1
1.1	1.6	0.8	-0.3	-0.5	-0.1
1.1	0.6	1.0	-0.2	-0.4	-0.1
1.1	2.2	0.7	-0.2	-0.5	-0.1
1.3	0.7	0.6	-0.2	-0.5	-0.2
0.2	1.7	0.7	-0.2	-0.4	-0.2
0.3	3.7	1.0	0.0	-0.2	0.1

4. Conclusions

In order to alter the traditionally empirical decision model and improve the scientificity and rationality of production decision of bauxite mine in the new normal, this article initially conducts the research integrating three phases: mine preparation, cleaning, transportation and marketing, into one production system; constructs the optimal production decision model of multiple-bauxite product portfolio for minimum cost, and takes 6 mine deposits as the research objects for empirical research.

The major conclusions are as follows: (1) the multi-mine and multi-product production decision model can realize the minimum cost and equilibrium profit allocation; help bauxite mine enterprises to effectively improve the profitability and severe loss of part of bauxite mines; (2) results show that rational adjustment of production schedule and product portfolio production structure can effectively lower down the

Continution on page 302