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Productive Utilization of Natural Resources.

– An Optimization Approach from different prospective for utilization of Chrome Ore

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Introduction

It is always preferred to use uniform high grade ore for production of metallic alloy. But in real life situation, it is not possible to get a homogeneous ore. Chrome ore is one of the precious natural resources having limited availability. The chemical composition of the ore varies horizontally and vertically across the ore body in mines. The ore quality is not uniform in all the faces of the mines. The production requirement being uniform grade of ore, blending of different grades of ore is required at the mines head before using it in the furnaces for smelting. The production requirement is to have a uniform grade metal production to meet the customer specification with minimum or zero deviation.

Further, Chrome ore being one of the precious natural resources need to be preserved and used properly; the low and or medium grade ore should be used by suitably blending with the high grade ore instead of misusing.

Present Practice

The important chemical parameters of the chrome ore are Cr_2O_3, Cr/Fe, F_eO, Al_2O_3, Phos, SiO_2, CaO, M_gO and Cost ore. Each chemical parameter is having some lower and upper limit for being suitable to be used for Ferro Chrome production. The requirement being uniform, higher grade of ore having uniform chemical composition, this requirement forced to mine only high-grade ore, thereby creating a huge stock of other medium and lower grade of ore at mines pit. This not only affects the mines operation but also leads to the wastage of natural resources.

Considering the practical problems of reduction in cost of alloy production, preservation and use of high-grade ore and enhanced value addition by using the medium and low-grade ores, a mathematical model of non-linear nature has been developed. The model was formulated for blending of chrome ore from different lots with three different objective functions. The objective functions are

1. Maximizing the quantity of ore supply
2. Minimizing the cost of Ore.
3. Maximizing the satisfaction index

Maximize the quantity of supply:

The problem formulated with an objective of maximizing the quantity of supply from the available lots of ore subject to fulfilling the chemical parameters. The particulars of the model are as under.

Objective Function **Maximize Z=** $\sum_{i=1}^{n} Qi$ *(Maximize the quantity of supply)*

Q_i = Quantity of ore from Lot *(i)*

The Constraints being

$Qi \leq Q_{si}$ **(**Quantity considered for blending should be less than the availability)

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Q_{si}= Availability (stock) of ore in lot *(i)*

$$\sum_{i=1}^{n} \frac{Cr_2O_3 \times Q_i}{Q_i} \geq Lower.Limit.of.Cr_2O_3 \quad \text{and} \quad \sum_{i=1}^{n} \frac{Cr_2O_3 \times Q_i}{Q_i} \leq Upper.Limit.of.Cr_2O_3$$

Weighted average Cr_2O_3 % in ore should be less than the upper limit and more than the lower limit.

$$\sum_{i=1}^{n} \frac{F_eO \times Q_i}{Q_i} \geq Lower.Limit.of.F_eO \quad \text{and} \quad \sum_{i=1}^{n} \frac{F_eO \times Q_i}{Q_i} \leq Upper.Limit.of.F_eO$$

Weighted average FeO % in ore should be less than the upper limit and more than the lower limit.

$$\sum_{i=1}^{n} \frac{S_iO_2 \times Q_i}{Q_i} \leq Upper.Limit.of.S_iO_{2.} \quad \text{and} \quad \sum_{i=1}^{n} \frac{S_iO_2 \times Q_i}{Q_i} \geq Lower.Limit.of.S_iO_{2.}$$

Weighted average SiO_2 % in ore should be less than the upper limit and more than the lower limit.

$$\sum_{i=1}^{n} \frac{Al_2O_3 \times Qi}{Qi} \geq Lower.Limit.of.Al_2O_3. \quad \text{and} \quad \sum_{i=1}^{n} \frac{Al_2O_3 \times Q_i}{Q_i} \leq Upper.Limit.of.Al_2O_3.$$

Weighted average Al_2O_3 % in ore should be less than the upper limit and more than the lower limit.

$$\sum_{i=1}^{n} \frac{C_aO \times Q_i}{Q_i} \geq Lower.Limit.of.C_aO \quad \text{and} \quad \sum_{i=1}^{n} \frac{C_aO \times Q_i}{Q_i} \leq Upper.Limit.of.C_aO$$

Weighted average CaO % in ore should be less than the upper limit and more than the lower limit.

$$\sum_{i=1}^{n} \frac{M_gO \times Q_i}{Q_i} \geq Lower.Limit.of.M_gO \quad \text{and} \quad \sum_{i=1}^{n} \frac{M_gO \times Q_i}{Q_i} \leq Upper.Limit.of.M_gO$$

Weighted average MgO % in ore should be less than the upper limit and more than the lower limit.

$$\sum_{i=1}^{n} \frac{P_h \times Q_i}{Q_i} \geq Lower.Limit.of.Phos \quad \text{and} \quad \sum_{i=1}^{n} \frac{P_h \times Q_i}{Q_i} \leq Upper.Limit.of.Phos$$

Weighted average Phos % in ore should be less than the upper limit and more than the lower limit.

$$\sum_{i=1}^{n} \frac{(Cr/Fe) \times Qi}{Q_i} \geq Lower.Limit.of(Cr/Fe) \quad \text{and} \quad \sum_{i=1}^{n} \frac{(Cr/Fe) \times Qi}{Q_i} \leq Upper.Limit.of(Cr/Fe)$$

Weighted average Cr/Fe in ore should be less than the upper limit and more than the lower limit.

Typical stocks of different lots of chromium ore available with the upper and lower limit specification for acceptance are as shown in table 1

Table 1 Different grade of chromium ore and its chemical composition

MATERIAL	Quantity Stock (MT)	Cost Rs/MT	Cr2O3 %	FeO %	SiO2 %	Al2O3 %	CaO %	MgO %	Ph %	Cr/Fe
Lot-1	1000	250	42.70	18.80	3.20	13.36	2.25	8.02	0.013	2.00
Lot-2	2000	275	48.00	15.23	3.20	13.46	3.75	7.25	0.013	2.78
Lot-3	3000	275	46.00	18.02	5.00	13.90	1.50	8.00	0.010	2.25
Lot-4	1500	250	43.00	17.17	3.20	12.23	2.25	8.00	0.013	2.21
Lot-5	7000	250	46.00	16.81	3.68	17.04	0.98	9.58	0.010	2.41
Lot-6	2000	250	44.00	23.10	3.68	14.87	0.98	9.58	0.010	1.68
Lot-7	3000	275	48.00	16.81	3.68	17.04	0.98	9.58	0.010	2.52
Lot-8	1500	275	46.00	23.10	3.68	14.87	0.98	9.58	0.010	1.76
Lot-9	7000	250	43.00	11.42	15.15	8.92	1.02	18.81	0.007	3.32
Lot-10	10000	350	50.00	12.57	6.00	8.92	1.02	18.81	0.007	3.51
TOTAL	38000	279	46.41	17.30	4.00	13.43	1.73	10.43	0.011	2.47
UPPER LIMIT		350	47.00	18	4.00	13.50	2.50	14.00	0.013	2.50
LOWER LIMIT		250	46.0	16.0	3.5	9.00	1.0	7.0	0.000	2.2

The problem formulation in case of maximizing the quantity available considering the above available data can be as under.

$Z = \text{Maximize } (Q_1+Q_2+Q_3+\ldots\ldots\ldots\ldots\ldots +Q_{10})$

Where Q_1, Q_2, $Q_3\ldots\ldots\ldots Q_{10}$ are the quantity of material selected for blending from lot-1, lot-2, Lot-3 and lot-10 respectively

Constraints for quantity availability (Quantity considered for blending should be less than or equal with the availability)

Q_1<= 1000 MT, Q_2<=2000 MT, Q_3<=3000 MT, Q_4<=1500 MT, Q_5<=7000 MT

Q_6<=2000 MT , Q_7<=3000 MT, Q_8<=1500 MT, Q_9<=7000 MT, Q_{10}<=10000 MT

Constraints for Cr_2O_3 % in the Ore

$$(0.427Q_1+0.48Q_2+0.46Q_3+0.43Q_4+0.46Q_5+0.44Q_6+0.48Q_7+0.46Q_8+0.43Q_9+0.50Q_{10}) / (Q_1+Q_2+Q_3\ldots\ldots+Q_{10}) >=0.46$$

$$(0.427Q_1+0.48Q_2+0.46Q_3+0.43Q_4+0.46Q_5+0.44Q_6+0.48Q_7+0.46Q_8+0.43Q_9+0.50Q_{10}) / (Q_1+Q_2+Q_3\ldots\ldots+Q_{10}) <=0.47$$

Weighted average Cr_2O_3 % in ore should be less than the upper limit and more than the lower limit.

Constraints for FeO % in the Ore

$$(0.188Q_1+0.1523Q_2+0.1802Q_3+0.1717Q_4+0.1681Q_5+0.231Q_6+0.1681Q_7+0.231Q_8+0.1142Q_9+0.1257Q_{10}) / (Q_1+Q_2+Q_3+\ldots\ldots+Q_{10}) >=0.16$$

$$(0.188Q_1+0.1523Q_2+0.1802Q_3+0.1717Q_4+0.1681Q_5+0.231Q_6+0.1681Q_7+0.231Q_8+0.1142Q_9+0.1257Q_{10}) /(Q_1+Q_2+Q_3+\ldots\ldots+Q_{10}) <=0.18$$

Weighted average FeO % in ore should be less than the upper limit and more than the lower limit.

Constraints for SiO_2 % in the Ore

$$(0.032Q_1+0.032Q_2+0.05Q_3+0.032Q_4+0.0368Q_5+0.0368Q_6+0.0368Q_7+0.0368Q_8+0.1515Q_9+0.06Q_{10}) / (Q_1+Q_2+Q_3\ldots\ldots+Q_{10}) >=0.035$$

$$(0.032Q_1+0.032Q_2+0.05Q_3+0.032Q_4+0.0368Q_5+0.0368Q_6+0.0368Q_7+0.0368Q_8+0.1515Q_9+0.06Q_{10}) / (Q_1+Q_2+Q_3\ldots\ldots+Q_{10}) <=0.04$$

Weighted average SiO_2 % in ore should be less than the upper limit and more than the lower limit.

Constraints for Al_2O_3% in the Ore

$(0.1336Q_1+0.1346Q_2+0.139Q_3+0.1223Q_4+0.1704Q_5+0.1487Q_6+0.1704Q_7+0.1487Q_8+0.0892Q_9+0.0892Q_{10}) / (Q_1+Q_2+Q_3\ldots\ldots+Q_{10}) >=0.09$

$(0.1336Q_1+0.1346Q_2+0.139Q_3+0.1223Q_4+0.1704Q_5+0.1487Q_6+0.1704Q_7+0.1487Q_8+0.0892Q_9+0.0892Q_{10}) / (Q_1+Q_2+Q_3\ldots\ldots+Q_{10}) <=0.135$

Weighted average Al_2O_3 % in ore should be less than the upper limit and more than the lower limit.

Constraints for CaO% in the Ore

$(0.0225Q_1+0.0375Q_2+0.015Q_3+0.225Q_4+0.0098Q_5+0.0098Q_6+0.0.0098Q_7+0.0098Q_8+0.0102Q_9+0.0102Q_{10}) / (Q_1+Q_2+Q_3\ldots\ldots+Q_{10}) >=0.01$

$(0.0225Q_1+0.0375Q_2+0.015Q_3+0.225Q_4+0.0098Q_5+0.0098Q_6+0.0.0098Q_7+0.0098Q_8+0.0102Q_9+0.0102Q_{10}) / (Q_1+Q_2+Q_3\ldots\ldots+Q_{10}) <=0.025$

Weighted average CaO % in ore should be less than the upper limit and more than the lower limit.

Constraints for MgO % in the Ore

$(0.0802Q1+0.0725Q2+0.08Q3+0.08Q4+0.0958Q5+0.0958Q6+0.0.0958Q7+0.0958Q8+0.1881Q9+0.1881Q10) / (Q1+Q2+Q3\ldots\ldots+Q10) >=0.07$

$(0.0802Q_1+0.0725Q_2+0.08Q_3+0.08Q_4+0.0958Q_5+0.0958Q_6+0.0.0958Q_7+0.0958Q_8+0.1881Q_9+0.1881Q_{10}) / (Q_1+Q_2+Q_3\ldots\ldots+Q_{10}) <=0.14$

Weighted average MgO % in ore should be less than the upper limit and more than the lower limit.

Constraints for Phos % in the Ore

$(0.00013Q_1+0.00013Q_2+0.0001Q_3+0.00013Q_4+0.0001Q_5+0.0001Q_6+0.0.0001Q_7+0.0001Q_8+0.00007Q_9+0.00007Q_{10}) / (Q_1+Q_2+Q_3\ldots\ldots+Q_{10}) >=0.00001$

$(0.00013Q_1+0.00013Q_2+0.0001Q_3+0.00013Q_4+0.0001Q_5+0.0001Q_6+0.0.0001Q_7+0.0001Q_8+0.00007Q_9+0.00007Q_{10}) / (Q_1+Q_2+Q_3\ldots\ldots+Q_{10}) <=0.00013$

Weighted average Phos % in ore should be less than the upper limit and more than the lower limit.

Constraints for Cr/Fe in the Ore

$(2Q_1+2.78Q_2+2.25Q_3+2.21Q_4+2.41Q_5+1.68Q_6+2.52Q_7+1.76Q_8+3.32Q_9+3.51Q_{10})/ (Q_1+Q_2+Q_3\ldots\ldots+Q_{10}) >=2.2$

$(2Q_1+2.78Q_2+2.25Q_3+2.21Q_4+2.41Q_5+1.68Q_6+2.52Q_7+1.76Q_8+3.32Q_9+3.51Q_{10})/ (Q_1+Q_2+Q_3\ldots\ldots+Q_{10}) <=2.8$

Weighted average Cr/Fe in ore should be less than the upper limit and more than the lower limit.

The problem was solved by using excel solver optimizer and the output of the optimization has been summarized in table 2

Table 2 Output of the optimization with objective function of maximizing the availability

MATERIAL	Quantity Stock (MT)	Optimum Quantity(MT)	Cost of Ore Rs/MT	Cr2O3 %	FeO %	SiO2 %	Al2O3 %	CaO %	MgO %	Ph %	Cr/Fe
Lot-1	1000	**1000**	250	42.70	18.80	3.20	13.36	2.25	8.02	0.013	2.00
Lot-2	2000	**2000**	275	48.00	15.23	3.20	13.46	3.75	7.25	0.013	2.78
Lot-3	3000	**0**	275	46.00	18.02	5.00	13.90	1.50	8.00	0.010	2.25
Lot-4	1500	**1500**	250	43.00	17.17	3.20	12.23	2.25	8.00	0.013	2.21
Lot-5	7000	**2874**	250	46.00	16.81	3.68	17.04	0.98	9.58	0.010	2.41
Lot-6	2000	**2000**	250	44.00	23.10	3.68	14.87	0.98	9.58	0.010	1.68
Lot-7	3000	**26**	275	48.00	16.81	3.68	17.04	0.98	9.58	0.010	2.52
Lot-8	1500	**1500**	275	46.00	23.10	3.68	14.87	0.98	9.58	0.010	1.76
Lot-9	7000	**0**	250	43.00	11.42	15.15	8.92	1.02	18.81	0.007	3.32
Lot-10	10000	**2824**	350	50.00	12.57	6.00	8.92	1.02	18.81	0.007	3.51
TOTAL QUANTITY		**13723**	**277**	**46.26**	**17.50**	**4.00**	**13.50**	**1.62**	**10.85**	**0.010**	**2.46**

	Cost	Cr2O3	FeO	SiO2	Al2O3	CaO	MgO	Ph	Cr/Fe
UPPER LIMIT	350	47.00	18	4.00	13.50	2.50	14.00	0.013	2.80
LOWER LIMIT	250	46.0	16.0	3.5	9.0	1.0	7.0	0.000	2.2

The table shows that the optimum quantities (Q_i) of ore selected from different lots in order to maximize the availability are

Lot-1	Q_1	1000 MT	Lot-2	Q_2	2000 MT
Lot-3	Q_3	0 MT	Lot-4	Q_4	1500 MT
Lot-5	Q_5	2874 MT	Lot-6	Q_6	200 MT
Lot-7	Q_7	26 MT	Lot-8	Q_8	1500 MT
Lot-9	Q_9	0 MT	Lot-10	Q_{10}	2824 MT

Average Chemical composition of ore against the upper and lower limits under.

	Cr_2O_3	FeO	SiO_2	Al_2O_3	CaO	MgO	Ph	Cr/Fe
Upper limit	47.00	18	4.00	13.50	2.50	14.00	0.013	2.80
Lower Limit	46.0	16.0	3.5	9.0	1.0	7.0	0.000	2.2
Actual with above ore mix	46.26	17.50	4.00	13.50	1.62	10.85	0.010	2.46

The average cost of the above blended ore is Rs 277 per metric tonne.

Minimize the cost of Ore

The problem formulated with an objective of minimizing the cost of ore supply from the available lots of ore subject to fulfilling the minimum quantity and chemical parameters requirement. The particulars of the model are as under.

Objective Function = Minimize the cost of Ore

Objective Function Minimize Z= $\sum_{i=1}^{n} \frac{Q_i \times C_i}{Q_i}$

Q*i* = Quantity of ore from Lot *(i)*

Ci is the cost of Mining of the ore from Lot *(i)*

The Constraints being

$Qi \leq Qsi$ **(**Quantity considered for blending should be less than the availability)

Q*si* = Availability (stock) of ore in lot *(i)*

Constraints for all quality parameters being same as in the same of maximizing the quantity of ore supply

The problem formulation in case of minimizing the cost of ore supply from the available lots of ore subject to fulfilling the minimum quantity and chemical parameters requirement. The problem formulation using the data available in Table-10 can be as shown below.

$Z=Min\ (250Q_1+275Q_2+275Q_3+250Q_4+250Q_5+250Q_6+275Q_7+275Q_8+250Q_9+350Q_{10})$
Where Q_1, Q_2, Q_3……Q_{10} are the quantity of material from lot-1, lot-2, lot-3 and lot-10 respectively.

The constraints of the model being same as that of the maximizing the quantity problem. The output of the optimization has been summarized in table 3

Table 3 Output of the optimization with objective function of minimizing the average cost of ore.

MATERIAL	Quantity Stock (MT)	Optimum Quantity(MT)	Cost of Ore Rs/MT	Cr2O3 %	FeO %	SiO2 %	Al2O3 %	CaO %	MgO %	Ph %	Cr/Fe
Lot-1	**1000**	**1000**	250	42.70	18.80	3.20	13.36	2.25	8.02	0.013	2.00
Lot-2	**2000**	**2000**	275	48.00	15.23	3.20	13.46	3.75	7.25	0.013	2.78
Lot-3	**3000**	**0**	275	46.00	18.02	5.00	13.90	1.50	8.00	0.010	2.25
Lot-4	**1500**	**1500**	250	43.00	17.17	3.20	12.23	2.25	8.00	0.013	2.21
Lot-5	**7000**	**2541**	250	46.00	16.81	3.68	17.04	0.98	9.58	0.010	2.41
Lot-6	**2000**	**1893**	250	44.00	23.10	3.68	14.87	0.98	9.58	0.010	1.68
Lot-7	**3000**	**0**	275	48.00	16.81	3.68	17.04	0.98	9.58	0.010	2.52
Lot-8	**1500**	**0**	275	46.00	23.10	3.68	14.87	0.98	9.58	0.010	1.76
Lot-9	**7000**	**97**	250	43.00	11.42	15.15	8.92	1.02	18.81	0.007	3.32
Lot-10	**10000**	**1969**	350	50.00	12.57	6.00	8.92	1.02	18.81	0.007	3.51
TOTAL QUANTITY		**11000**	**272**	**46.00**	**17.03**	**4.00**	**13.50**	**1.78**	**10.53**	**0.01**	**2.49**
Material Req	**11000**	UPPER LIMIT	350	47.00	18	4.00	13.50	2.50	14.00	0.013	2.80
		LOWER LIMIT	250	46.0	16.0	3.5	9.0	1.0	7.0	0.0	2.2

The table shows that the optimum quantities (Q_i) of ore selected from different lots in order to minimize the cost are

Lot-1	Q_1	1000	MT	Lot-2	Q_2	2000	MT
Lot-3	Q_3	0	MT	Lot-4	Q_4	1500	MT
Lot-5	Q_5	2541	MT	Lot-6	Q_6	1893	MT
Lot-7	Q_7	0	MT	Lot-8	Q_8	0	MT
Lot-9	Q_9	97	MT	Lot-10	Q_{10}	1969	MT

Average Chemical composition of ore against the upper and lower limits under.

	Cr_2O_3	FeO	SiO_2	Al_2O_3	CaO	MgO	Ph	Cr/Fe
Upper limit	47.00	18	4.00	13.50	2.50	14.00	0.013	2.80
Lower Limit	46.0	16.0	3.5	9.0	1.0	7.0	0.000	2.2
Actual with above ore mix	46.00	17.03	4.00	13.50	1.78	10.53	0.01	2.49

The average cost of the above blended ore is Rs 272 per metric tonne. Where the present cost of ore is about Rs.290

Maximizing the User satisfaction Index:

The user requirement is a homogeneity ore with higher metallic content and less of impurities available at low cost. There are few elements of ore, higher the value of which results in higher level of user satisfaction. Parameters Cr_2O_3, FeO, Cr/Fe, CaO, SiO_2 and MgO fall in this category. The other category where lower the value, higher is the satisfaction are Al_2O_3, Phos and Cost of Ore.

Objective Function – Maximizing the User satisfaction Index.

Objective Function Maximize Z= $\sum_{j=1}^{n} D_j \times W_j$

D_j – Satisfaction index of the parameter (j)
W_j – Weighatage of the Parameter (j)
The Constraints being
$Q_i \leq Q_{si}$ **(**Quantity considered for blending should be less than the availability)
Q_{si}= Availability (stock) of ore in lot *(i)*
Q_i = Quantity of ore from Lot *(i)*

Constraints for all quality parameters being same as in the same of maximizing the quantity of ore supply

To decide on the user satisfaction index the parameters of the ore be divided in to two broad categories as

Category-1: Higher the value of the parameter higher is the level of user satisfaction. Parameters falling in category- 1 are Cr_2O_3, FeO, Cr/Fe, CaO, SiO_2 and MgO
Category-2: Higher the value of the parameter Lower is the level of user satisfaction. Parameters falling in category- 2 are Al_2O_3, Phos and Cost of Ore

Each parameter is having lower and upper limit. Let *Rj* be the range of the parameter, i.e., (difference of the maximum and minimum limit). The satisfaction index for each parameter has been divided in a five-point scale as follows.

		Satisfaction index Category-1	Satisfaction index Category-2
Actual Parameter	>= Lower Limit <= Lower Limit + *Rj*/5	*(Di)*=1	*(Di)* =5
Actual Parameter	>= Lower Limit + *Rj*/5 <= Lower Limit + 2*Rj*/5	*(Di)*=2	*(Di)* =4
Actual Parameter	>= Lower Limit + 2*Rj*/5 <= Lower Limit + 3*Rj*/5	*Di*) =3	*Di*) =3
Actual Parameter	>= Lower Limit + 3*Rj*/5 <= Lower Limit + 4*Rj*/5	*(Di)* =4	*(Di)*=2
Actual Parameter	>= Lower Limit + 4*Rj*/5	*(Di)* =5	*(Di)*=1

Weightages of the Parameters

Based on the feed back from the furnace operators the weightages for the different parameters *(Wj)* for comfortable operation has been decided as under.

Parameters	Weightage
Cr_2O_3	0.30
Cr/Fe	0.20
FeO	0.10
Cost	0.10
Al_2O_3	0.075
Ph	0.075
SiO_2	0.05
CaO	0.05
MgO	0.05

The problem formulation in case of maximizing the satisfaction index can be formulated as under

Z=Maximize (30% Satisfaction index Cr_2O_3 +20% Satisfaction index *Cr/Fe* +10% Satisfaction index *FeO*+10% Satisfaction index *Cost*+7.5% Satisfaction index Al_2O_3 +7.5% Satisfaction index *Ph*+5% Satisfaction index SiO_2+5% Satisfaction index *CaO*)

The constraints are same as that of the maximizing the quantity problem. The problem was solved and the output of the model is presented in table 4

Table 4. Output of the model of maximizing user satisfaction index.

MATERIAL	Quantity Stock (MT)	**Blending Quantity**	Cost Rs/MT	Cr2O3 %	FeO %	SiO2 %	Al2O3 %	CaO %	MgO %	Ph %	Cr/Fe
Lot-1	1000	**1000**	250	42.70	18.80	3.20	13.36	2.25	8.02	0.013	2.00
Lot-2	2000	**1670**	275	48.00	15.23	3.20	13.46	3.75	7.25	0.013	2.78
Lot-3	3000	**699**	275	46.00	18.02	5.00	13.90	1.50	8.00	0.010	2.25
Lot-4	1500	**1500**	250	43.00	17.17	3.20	12.23	2.25	8.00	0.013	2.21
Lot-5	7000	**921**	250	46.00	16.81	3.68	17.04	0.98	9.58	0.010	2.41
Lot-6	2000	**639**	250	44.00	23.10	3.68	14.87	0.98	9.58	0.010	1.68
Lot-7	3000	**1156**	275	48.00	16.81	3.68	17.04	0.98	9.58	0.010	2.52
Lot-8	1500	**1433**	275	46.00	23.10	3.68	14.87	0.98	9.58	0.010	1.76
Lot-9	7000	**0**	250	43.00	11.42	15.15	8.92	1.02	18.81	0.007	3.32
Lot-10	10000	**1982**	350	50.00	12.57	6.00	8.92	1.02	18.81	0.007	3.51
TOTAL	38000	11000	279	46.41	17.30	4.00	13.43	1.73	10.43	0.011	2.47
UPPER LIMIT		**38000**	350	47.00	18	4.00	13.50	2.50	14.00	0.013	2.80
LOWER LIMIT		**10000**	250	46.0	16.0	3.5	9.00	1.0	7.0	0.000	2.2
Weighatage			10.0%	30.0%	10.0%	5.0%	7.5%	5.0%	5.0%	7.5%	20.0%
	(out of 5)		3.00	3.00	4.00	5.00	1.00	3.00	3.00	1.00	3.00
SATISFACTION INDEX		**2.90**									

The table shows that the optimum quantity ***(Q_i)*** of ore selected from different lots in order to maximizing user satisfaction index.

Lot-1	Q_1	1000 MT	Lot-2	Q_2	1670 MT
Lot-3	Q_3	699 MT	Lot-4	Q_4	1500 MT
Lot-5	Q_5	921 MT	Lot-6	Q_6	639 MT
Lot-7	Q_7	1156 MT	Lot-8	Q_8	1433 MT
Lot-9	Q_9	0 MT	Lot-10	Q_{10}	1982 MT

Average Chemical composition of ore against the upper and lower limits under.

	Cr_2O_3	*FeO*	SiO_2	Al_2O_3	*CaO*	*MgO*	*Ph*	*Cr/Fe*
Upper limit	47.00	18	4.00	13.50	2.50	14.00	0.013	2.80
Lower Limit	46.0	16.0	3.5	9.0	1.0	7.0	0.000	2.2

Actual with above ore mix	46.41	17.30	4.00	13.43	1.73	10.43	0.011	2.47

The average cost of the above blended ore is Rs 279 per metric tonne.

Summary and Observation

The output of the models having different objective functions are summarized and presented in table 4.12

Table 5 Output comparison from different objective functions

	Quantity (MT)	Cost (Rs/MT)	Cr2O3 %	FeO %	SiO2 %	Al2O3 %	CaO %	MgO %	Ph %	Cr/Fe
Maximising Quantity	13723	277	46.26	17.50	4.00	13.50	1.62	10.85	0.010	2.46
Minimising Cost	11000	272	46.00	17.03	4.00	13.50	1.78	10.53	0.011	2.49
Maximising Satisfaction Index	11000	279	46.41	17.30	4.00	13.43	1.73	10.43	0.011	2.47

There is a increase in cost of the ore in the output of maximizing quantity and maximizing satisfaction index from the out of the objective function of minimizing cost by Rs 5 and Rs 7 per MT respectively, the impact of which is Rs 62477 and Rs 75237. The impact can be derived as under

Impact of increasing in average cost of ore from the objective function of minimizing cost to the objective function of maximizing quantity = (272-277) Rs/MT x 13723MT = Rs (-) 62477/Month. Similarly the impact of increasing in average cost of ore from the objective function of minimizing cost to the objective function of maximizing satisfaction index =(272-279) Rs/MT x 11000MT = Rs (-) 75237/ Month

There is an increase in Cr_2O_3 % of the ore in the output of maximizing quantity and maximizing satisfaction index from the out of the objective function of minimizing cost by 0.26% and 0.41% respectively, the impact of which is Rs 8.08 lacs and Rs 12.80 lacs .

The impact can be derived as under

	Cr_2O_3 % in the Ore	% Increase from the Output of Minimizing Cost
Minimizing Cost	46%	------
Maximizing Quantity	46.26%	0.26%
Maximizing Satisfaction index	46.41%	0.41%

The impact of additional chromium input will lead to higher volume of production which can be derived as (Additional chromium input x Chromium recovery) / (% chromium in the finished goods)

Where Additional chromium input = Difference in Cr_2O_3 % x Conversion factor (0.685) x Quantity of ore in MT

Chromium Recovery = 83% & percentage (%) of Chromium in the finished good= 60%

In case of the output of maximizing quantity (0.0026 x 0.685 x 13723 x 0.83) / 0.6 = 26.94 MT and in case of the output of maximizing satisfaction index (0.0041 x 0.685 x 11000 x 0.83) / 0.6 = 42.66 MT respectively for maximizing quantity or maximizing satisfaction index respectively.

By valuing the additional production at the current market price @ Rs 30000 per MT the impact will be Rs 8.08 lacs and Rs 12.80 lacs. The net benefit by deducting the increasing in cost of ore from the output minimizing cost will be about Rs 7.45 lacs and Rs 12.04 lacs.

Conclusion

It is suggested to use the model with the objective function of maximizing the user satisfaction index. The model suggests a blend of available ore matching to all the elemental requirement of production. The low grade ore which was otherwise idle will get utilized in due course of time there by improving in productive use of natural resources without affecting the quality of the output. In addition, there is a significant improvement in the profitability of the organization.