Eco Efficient Value Addition Processes for Metallurgical Operations

Ayyakkannu*, P.C Naganoor, B.P. Ravi and P.Sharath Kumar
Department of Mineral processing, VSKU PG Centre Nandihalli-Sandur 583319

1. Abstract

The selection of location for geometallurgical operations like pelletization and Pig Iron manufacturing units depends on the design variables to satisfy sustainable process measure triangle inequality. When the selected location act as a facility location at later stage, the economic measures of the facilities called as determinants should have capability to satisfy all three conditions. The determinants of combined capital assets of pelletizing and pig iron processes are unable to satisfy these conditions when assets are located at non facilitating areas like port. The objective the paper is to resolve the metric facility location problem and to study the constraints as integral part of value addition methods. $\boldsymbol{\pi}$ Flow sheet with isosceles triangle, $\boldsymbol{\pi}$ inverse flow sheet with Pythogrean triples 3:4:5 and tangent triad are three tools used to measure the suitability of geometallurgical value addition process for metric facility location problem.

Key words: Triangle Inequality condition, $\boldsymbol{\pi}$ flow sheet, $\boldsymbol{\pi}$ Inverse flow sheet

2. Introduction

The port based merchant pelletizing and pig iron processes, though offers location flexibility for raw and finished materials, are unable to satisfy efficiency effectiveness status due to Non –compliance of triangle inequality condition applicable to metric facility location Non –compliance of triangle inequality condition applicable to metric facility location as constraints are inevitable. Since the existing intermediate value addition processes are insufficient to satisfy these conditions, exploration for additional value addition processes to resolve metric facility location problem on coastal area of Karnataka state. This has been proven time again by Japanese steel manufacturers over a period of time and recently in case of RINL, Vishakhapatnam.

The efficiency economic status of the port based geometallurgical operations like pellet and pig iron manufacturing units as in the present case are embedded with constraints like Eco Sensitive Port location (Facility location), Outsourcing of iron ore fines, lump and coke termed as High Value Resources Input (HVRI) and Modes of Transportation Facilties of Raw Materials (MTFRM).With above constraints, the global fall in steel price and marginal decline in demand (NSP 2017), the economic effectiveness or constraint function is expressed mathematically as follows:

$$Efficiency\ Effectiveness = \frac{\mathrm{MR1}}{\mathrm{Pcv}} < 1 \qquad (1)$$

Where: MR_1 = Market rate, P_{cv} = Product Cost value, values >1 indicate profit and <1 indicate loss

For Top end agglomeration process (pelletizing) the efficiency effectiveness is expressed as

$$Efficiency\ Effectiveness = \frac{\mathrm{MR1}}{\mathrm{Pcv}} < 1 \qquad (2)$$

For Reduction process by blast furnace (Pig iron) the efficiency effectiveness is expressed as

$$Efficiency\ Effectiveness = \frac{\mathrm{MR1}}{\mathrm{Pcv}} < 1 \qquad (3)$$

The Location Allocation Logistic Matrix (LALM) may be considered as “Probability to Loss making by value addition processes” . The satisfaction of constraints by effectiveness of the value addition processes are known as Constraints satisfaction.

3 Path Analysis

The Fig.1 represents the path analysis of the port based merchant pelletization and Pig Iron Process plant.

3.1 Metric Facility Location (MFL) and Triangle Inequality Condition (TIC):

When distances between clients and sites are not specified, triangle inequality condition not satisfied which leads to metric facility location problem. Further, the triangle inequality condition states that: “Sum of any two sides of triangle greater than third side”. Hence, the sum of the two sides of the triangle should be greater than third side to satisfy the triangular equality for sustainable operations.

3.2 Efficiency – Effectiveness:

The term Efficiency –Effectiveness refers to effectiveness of the process efficiency i.e. the logistics of the value addition processes should have capability to yield economic effectiveness when constrains are inevitable.

3.3 Confirmatory Factor Analysis (CFA):

In exploratory factor analysis, all measured variables are related to every latent variable. But in confirmatory factor analysis (CFA), the factors like location, Allocation and Logistics are considered as a measured variable is related to which latent variable. The matrix of current operation is given in Fig. 2.

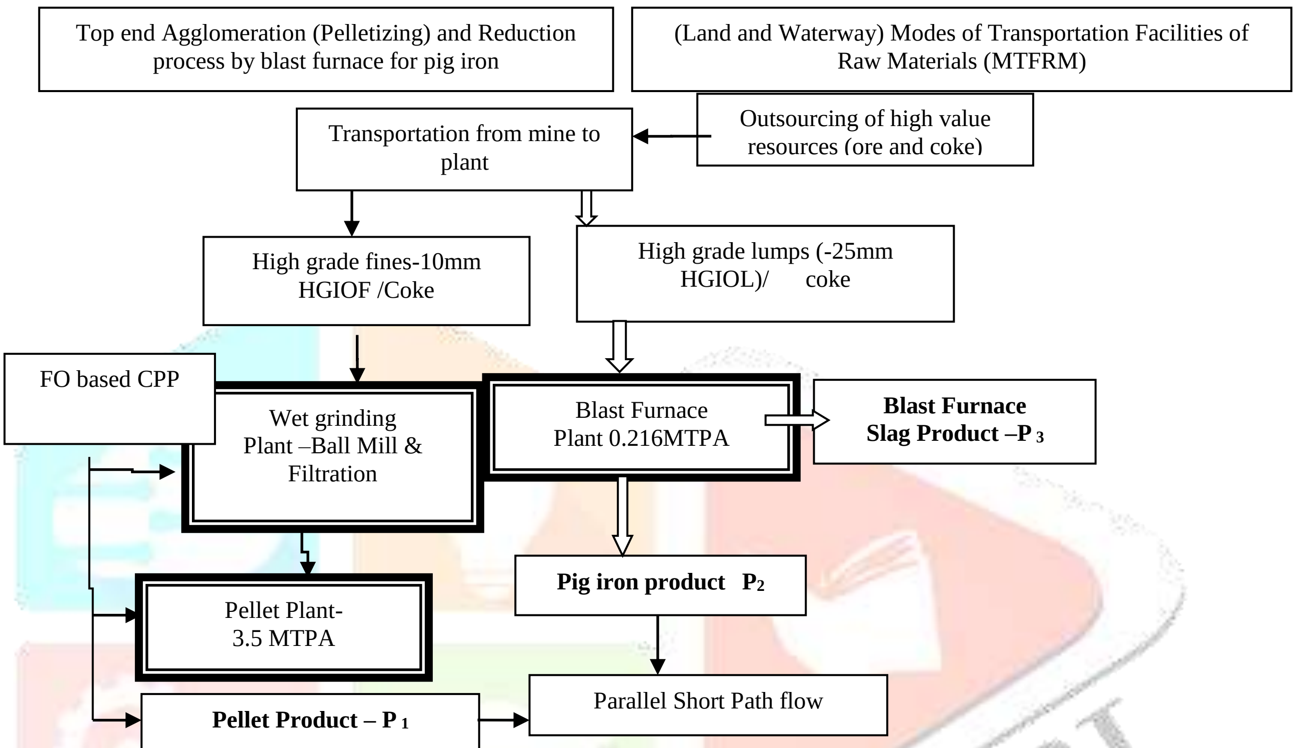


Fig.1; Pellet and Pig iron plants Flow sheet Logistics

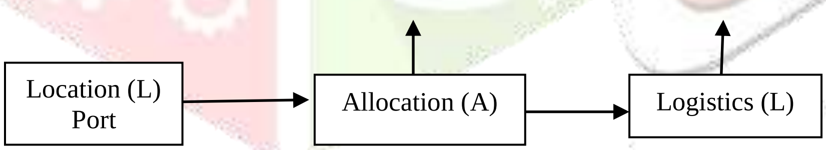


Fig 2: Matrix of present operation

4 Structural Equation Modeling (SEM) for LALM

When an enterprise operates Geometallurgical Intermediate Value Addition Process (GIVAP) like merchant pelletizing and pig iron processes at any sea port location and the processes can be expressed by SEM as:

SEM = E = GIVAP $= Q_{PRI} \times VAMs = Q_{o\,(P\,1,2\,+\,P\,3)} = (P_{1,2\,(CV)} \geq MR_1)$ and $(P_3 < MR_1) \neq (\square_{EL\,LOW} \rightarrow \square_{SEEL})$

SEM = Input function (E) $\neq$ Output function $(\square_{SEEL})$

$(P_{1,(CV)} >$ or $< MR_1)$ – Pelletizing - Probability

$(P_{2,(CV)} > MR_1)$ and $(P_{3\,(CV)} = MR_1)$ – Pig iron – Loss Making

The status with the constraint function, is unable to be fulfilled. When constraints are embedded, the product's cost value and sustainable level of the enterprise depends on:

$\mathbf{P_{CV} = Q_{PRI} \times VAMs = Q_{o\,(P\,1,2\,,\,3)}}$ **or** $P_{CV} = (Q_{HVRI-CV} + TP_{CV}) = (LC_{HVRI} + TP_{CV})$ = Landing Cost (LC) value of HVRI + Transformation processes (TP), Where HVRI – High Value Resources Input consisting of ore fines, lump and coke

4.1 Measurement of Efficiency – Effectiveness of LALM:

The efficiency – effectiveness or economic effectiveness of LALM = $P_{CV} < MR_1$. The " less than" status is depending on Efficiency Ratio and Eco efficiency, which are mentioned below.

Efficiency Ratio: The market rate is an extraneous factor and the enterprise may not have control on it. But the product's cost value depends on "enterprise mission – focus" and it's measured by efficiency ratio defined as:"

$P_{CV} = (LC_{HVRI} + P_{CV}) < MR_1$ where $MR_1 = P_{CV} +$ Profit= Product Sale Value=P_{SV}, Efficiency Ratio = $P_{CV} / P_{SV} < 1$

$$\text{Eco Efficiency } (\eta_{eco}) \text{ is defined as } = \frac{\textit{Economic realization}}{\text{Environmental inputs}} = \frac{\text{Transformation process } - TP_{CV}}{\text{Landing cost value } - LC_{HVRI}} = \frac{Q_O}{Q_{IO}} = P_{1,2.(Max)}$$

= π flow sheet (π_{FS}) and π Inverse flow sheet (π_{IFS}) , **(□EL - □ SEEL)** = $LALM_{E\,E}$ = (π_{FS}) and (π_{IFS})

5 Statistical Tools and Econometric Models

The statistical tools and econometric models for measuring the economic effectiveness and sustainability of value addition process are discussed below as enumerated by Surabhi (2015)

5.1 Statistical Tools:

The geometallury is the combination of Mining, mineral processing and metallurgy. The economic effectiveness and sustainable of the enterprise is measured by geometallurgy circle (GIVAP or GVAP) related to location, allocation, logistics matrix (LALM) is shown in Fig. 3. Geometallurgy viability = (Location – Allocation – Logistics Matrix) $_{\text{Efficiency - Effectiveness}}$

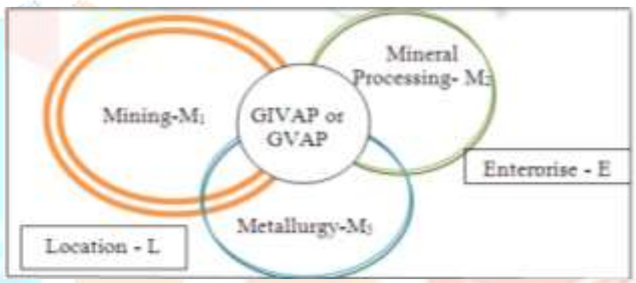


Fig 3: LALM of present operation

5.2 Econometric Models:

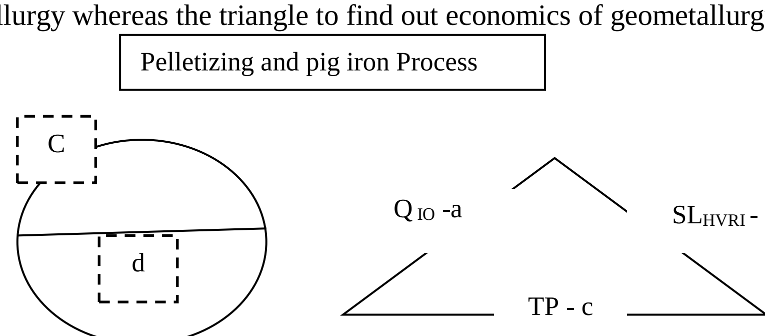
The Economic Model for LALM: Geometallurgy = Geometry = Trigonometry, Geometallurgy = Flow sheet (G_{FS}), Empirical tools: Geometry = Geometallurgy circle, Trigonometry = Triangle inequality conditions and right triangle Conditions. The empirical tools are Geometallurgy circle and Pythagorean triple consisting of (1) π flow sheet (π_{FS}) and isosceles right triangle conditions and (2) π Inverse flow sheet (π_{IFS}) and side based right triangle (3:4:5)

6.0 Descriptive Statics for Empirical Tools:

The brief description of empirical tools are enumerated below.

6.1 Determinants of π Flow sheet and isosceles right triangle conditions;

One of the salient features in this paper is the introduction of π Flowsheet ***or*** Pi flowsheet to transform geometallurgy flowsheet on plain surface into geometry shape of circle and triangle is shown in Fig.4. The circle represent geometallurgy whereas the triangle to find out economics of geometallurgy.



a- Quantity of iron ore fines or lump - Q_{IO} – Observed Variables or economic variables by quantity and cost

b- Standard Loss - SL_{HVRI} – Observed and Latent Variables (Non economic variables. It includes slag mineral, coke and transportation cost of high value resources input

c- Transformation processes (TP)- Observed variable or economic variable by quantity and cost

Diameter (d) – Primary Resource Input quantity – Q_{IO} or Output quantity - Q_O

Fig. 4; Determinants of π Flow sheet

The rationality of resources to value addition processes is given by π Flow sheet as shown here:

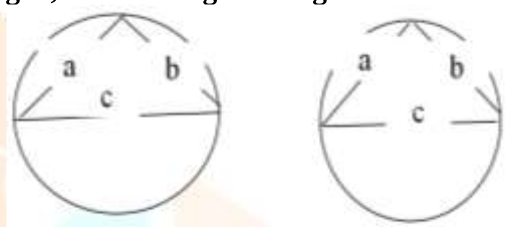
$$\pi = \frac{\text{Circumference (C)}}{\text{Diameter (d)}} = \frac{\text{Value addition methods (VAMs)}}{\text{Quantity } (Q_{O\,(P1,2\ldots)})} = \frac{\text{Cost}}{\text{Ton}}$$

$= 3.14 =$ design capacity (quantity – Q_O) = 100 %

6.1.1 Trigonometry by isosceles right triangle conditions: Right triangle condition states that:“Hypotenuse is greater than other two sides (base and opposite side) and less than their sum” and is mentioned as $c > a$ *or* b *and* $(a + b) \geq c$.The triangle inequality condition states that “Sum of any two sides is greater than third side”

(a +b) > c or(b +c) > a or (c + a) > b where a + b = Resources value and c = transformation value. The above triangle will be valid only if the transformation of raw material to value addition finished product increases as evidenced in global coast based integrated steel plants.Both triangle inequality condition and isosceles triangle conditions are contracting to each other in the present case, due to lack of finished valuable product in the present process flowsheet. The satisfaction depends on (1) Operating Expense Ratio (OER) (2) Efficiency Ratio (< 1) and (3) Eco efficiency (> 1). The determinants or Operating Expense Ratio (OER) are given by Isosceles right triangle conditions are :29.3 % : 29.3% : 41.4 %

Fig. 5; Isosceles right triangle conditions



Cost value of product (P_{CV}) = $Q_{IO-CV} + SL_{HVRI-CV} + TP_{CV}$ = 100 %

Efficiency Ratio = $P_{CV} / P_{SV} \geq 1$ for pelletizing and > 1 for pig iron process (marketability of the product)

$$\text{Cost per ton} = \frac{TP_{CV}}{Q_{IO-CV} + SL_{HVRI-CV}} = \text{Eco efficiency} = > 1$$

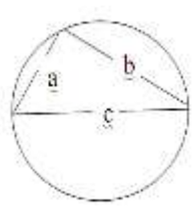
a = 29.3 % +29.3 % = 58.6%, b = 29.3 % +29.3 % = 58.6%, c = 41.4% + 41.4% = 82.8%

$$\text{Eco efficiency} = \frac{82.8\%}{117.2\ \%} = \frac{\text{(Top end agglomeration + Reduction by blast furnace)}}{\text{landing cost value}} = < 1$$

The technology (Top end agglomeration (Pelletizing) and reduction by blast furnace) requires 117.2% resources value for 82.8% of transformation processes. The triangle inequality condition is about Load – Distance (LD) and load is feed quantity (Q_{IO}) and coke travelling to a distance as per flow sheet. Therefore, triangle inequality condition is about flowsheet perimeter distance the feed quantity has to travel. The effects clearly indicate that the present technology of producing less valuable intermediate products, instead of value added premium finished products as elsewhere, is unable to satisfy Efficiency ratio condition (< 1) and Eco efficiency condition (>1)when constraints are inevitable.

6.1.2 π Inverse flow sheet and Side based right triangle (3:4:5 Ratio); Since pellet and pig iron plants are capitalized assets at port location, the path flow is also fixed. The capitalized assets are unable to satisfy efficiency ratio condition and eco efficiency condition. To overcome these problems, it is necessary to re-conceptualize the geometallurgy flow sheet as per Pi inverse flow sheet and side based right triangle (Ref. Fig 6)

Fig.6 Inverse flow sheet and Side based right triangle (3:4:5 Ratio)



1 Tons Diameter (d)

--- = ------- = 32% . = --

π Unit cost Circumference (C)– (Bottom end agglomeration + Reduction and oxidation processes)

The determinants of Pi inverse flow sheet are: Sizing of 100% in the ratio of 3:4:5. a= 25 % (iron ore resources-Max) b= 33% (standard Losses) c = 42% (Transformation processes)

Since pellet and pig iron are considered as "Low value – demand product" the high value product can be manufactured by new transformation processes (c) and is determined by efficiency ratio verses eco efficiency as:

Product cost value (P_{CV}) (Bottom end agglomeration + Reduction and Oxidation process)

Efficiency Ratio = ------------------------------- < 1= --

Products sale value (P_{SV}) iron grade and quantity

6.1.3 Eco Efficiency condition satisfaction by Majority Rule: The side based right triangle ratio is given as: 25% : 33% : 42%

$$\text{Eco efficiency} = \frac{42\,\%}{25\% + 33\%} = \frac{51\%\ \text{by cost}}{49\%\ \text{by cost}} > 1 = \frac{\text{Cost}}{\text{Ton}} < \text{Market Rate } (MR_1)$$

6.2 Evaluation of Cost per Ton by Tangent Triad and Right triangle condition satisfaction;

The evaluation of cost per ton or cost value of product (P_{CV}) can be done by Tangent Triad (9) method as explained here. Assume that a given weights of 100 units is rationalized for each observed and latent variable as per isosceles right triangle as shown here: Quantity of Iron ore Q_{IO}–a – 29.3% , Standard Losses SL) - b – 29,3% and Transformation Process (TP) - c – 41,4% .and for Side based right triangle (3:4:5) a – 25% , b – 33% and c – 42% . The results are tabulated in Table1.

Table 1; Evaluation of cost per ton

	Quantity of Iron ore Q_{IO}–a	Standard Losses (SL) -b	Transformation Process (TP) -c
Isosceles triangle	29.3 %	29.3%	41,4%
Side based triangle	25%	33%	42%

The perimeter of the triangle to the diameter of the circles determine the units,The number of units multiplied by Unit weight gives cost per ton (Details are separately given)

P_{CV} = Cost / ton = 50 units = 14.65% + 14.65% + 20.7% = x Rs100 = Rs 5,000 < or > MR_1 (Pellets)

P_{CV} = Cost / ton = 50 units = 14.65% + 14.65% + 20,7% x Rs 500 = Rs 25,000 > MR_1(Pig iron)

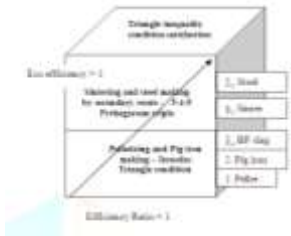
P_{CV} = Cost / ton = 50 units = 12.5% + 16.5% + 21% = x Rs 800 = Rs 40,000 = MR_1(Steel)

As per right angle triangle, the cost of pellets and pig iron unable to satisfy market rate condition whereas the side based right triangle satisfy the market rate for steel Metric facility location condition (triangle inequality) can able to satisfy by side based right triangle and majority rule. Metric facility location condition satisfaction can take place if Trifurcations of iron ore and πInverse flow sheet and side based right triangle conditions making value added steel. Incidentally, Joseph (2015) recommended sintering, a well known complimentary iron ore agglomeration process to pelletization needs to be added in agglomeration to reduce the agglomeration costs and internal use of agglomerate in pig iron making followed by value added steel making to make the merchant steel making plants sustainable.

7. Results and Discussion

The technology of pelletizing and pig iron processes require high value resources to meet the design capacity and the products unable to meet price competition. The value addition processes are stamped as "probability and loss making value addition processes" when these facilities are located at port. Therefore pelletizing and iron making flow sheet do not sufficient for triangle inequality condition satisfaction. Increasing product portfolio by 3:4:5 Pythagorean triple is the option to satisfy triangle inequality condition. This option involves capital investment to include steel making by primary or secondary methods as shown in Fig7.The Rastriya Ispat Nigam (RINt) at Vishakapatnam and Aryan steel at Navi Mumbai (net) are successfully manufacturing steel at Indian port location with characterizations of Land and Waterways Modes of Raw Material Transportation Facilities LWMRMTF. There are any more plants like Kobe steel are operating Iron and steel plant at port location around the world.

Fig 7; Eco efficient process model for LWMRMTF



8 Conclusion

Pelletizing and pig iron value addition processes are insufficient to satisfy efficiency ratio and eco efficiency ratio conditions when constraints are inevitable. It is recommended for linearization of Premium value steel making process for conditions satisfaction.

References

1. National Steel policy (NSP) 2017, Ministry of steel.gov.in/sites/National Steel Policy-2017.
2. Wikipedia, 2018, Facility Location problem. https://en Wikipedia.org/wiki/
3. Pietre Stones, 2018, Interesting properties of right triangles, www. freemasonary.com
4. https:/www.investopedia.com, 2018 How is marginal revenue related to the marginal cost of production
5. Joseph J. Poveromo, 2015, Raw Materials & Iron making Global, Proc. USGS Seminar, July 22, 2015, Reston, VA.
6. Surabhi, S. 2013,Difference between efficiency and effectiveness, https://keydifferences.com