

Optimizing Product Mix under Cane and Distillery Constraints: A Graphical Linear-Programming Study of Balrampur Chini Mills and Triveni Engineering

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Abstract:

In this paper, the graphical linear programming approach followed in the reference case study on a small Indonesian furniture workshop (Zentha Meubel) is replicated and applied in two Indian sugar-and-ethanol manufacturing firms (Balrampur Chini Mills (BCML) and Triveni Engineering & Industries). In the reference study, the owner decided between cabinets and tables based on restrictions on wood and working hours. Each firm decides how much sugarcane to be processed via the sugar route (x) and how much to be processed via the syrup-ethanol route (y), subject to two constraints: cane crushed during the season and surplus distillery capacity. Inputs are based on FY2024-25 data available in company filings (primary source) and government ethanol prices, a news article, and a secondary source on sugar industries. From the corner point test, the optimal mix of BCML is found to be 74.67 lakh tons to sugar and 24.49 lakh tons to ethanol with a gross revenue of Rs 4,559 crore, compared to Rs 4,451 crore from the factual plan (+2.4%). The optimal mix of Triveni is 71.30 and 10.60 lakh tons to sugar and ethanol respectively with a gross revenue of Rs 3,569 crore, compared to Rs 3,469 crore. Ethanol is preferred only while its price stays above Rs 55.77 per litre (BCML) or Rs 53.61 per litre (Triveni), compared with the government syrup price of Rs 65.61. The model uses gross revenue and ignores conversion costs, so it shows the direction of the decision and not the exact profit.

Keywords— Linear programming; Graphical method; Corner point test; Sugar industry; Ethanol blending; Resource allocation.

I. Introduction

Operations Research (OR) helps managers decide how to use limited resources such as raw material, machine time, labour and money. Linear programming (LP) is its most common tool. An LP has three parts: decision variables (what we choose), an objective function (what we want to maximise or minimise) and constraints (the limits we must respect).

This paper follows a published case study by Palayukan [1], who used the graphical method to find the best monthly output of 2-door cabinets and half-bureau tables at Zentha Meubel, a small furniture workshop in Tana Toraja, Indonesia. That study had two products, two constraints (wooden planks and working hours) and a corner-point test. We keep the

same method and the same seven steps, but we replace the workshop with two large listed Indian companies, Balrampur Chini Mills Ltd (BCML) and Triveni Engineering & Industries Ltd (Triveni).

We selected the sugar industry as the industry faced the dilemma of having a true two-product decision. The mill has two choices either to process the sugarcane into sugar or divert some of the juice/syrup to produce ethanol under the country's program of Ethanol Blended Petrol. Both these activities require the same raw material of limited availability, while the production of ethanol requires distillery capacity as well. It was reported in BCML's own presentation that about 18.36% ethanol blending has been achieved till 31 March 2025 [2].

It is necessary to make an honest statement regarding the data sources. As mentioned earlier, the reference study used primary data sources (an interview and observation during the workshop). We cannot have interviews of the management of the listed company. In our case, the primary data sources are the filed documents of the respective companies in the form of results presentations and operational disclosures of FY2024-25. Secondary data sources are the prices of ethanol by the government in the respective documents, one news report on BCML's season and one industrial report on Triveni's distillery capacity.

II. Literature Review

In the case of Zentha Meubel that produced 9 cabinets and 15 tables a month, Palayukan [1] determined that the production of one cabinet provided a net profit of Rp 1,250,000 and a table - Rp 350,000. Moreover, the production of one cabinet needed 10 planks and 13 hours and one table - 4 planks and 6 hours. There were 150 planks and 208 working hours (26 days * 8 hours) in the workshop per month. Then we have the following linear programming model: maximise $Z = 1,250,000x + 350,000y$

subject to $10x + 4y \leq 150$,

$13x + 6y \leq 208$ and $x, y \geq 0$.

The corner points of the feasible region are the points A (0, 0), B (15, 0), C (8.5, 16.25) and D (0, 34.67) where $Z = 0$, Rp 18,750,000, Rp 16,312,500 and approximately Rp 12,133,300 correspondingly. Thus, the best corner point is the point B and, consequently, the study suggests producing 15 cabinets and 0 tables per month which increases the net monthly profit by Rp 2,250,000 from the existing Rp 16,500,000.

The study is valuable as an example in terms of all steps taken being clear. The research has limitations which we are trying to cope with. The research makes no demand constraint, hence, the production of only cabinets is unrealistic. It takes into account only one owner's figures on one-month period. The work calls the activity qualitative while the calculations are numerical. Therefore, we add the sensitivity test, the clear table of the source of the data used and the part about assumptions made by the model.

Much closer to our case study is the presentation of BCML's results of FY25 which shows that due to government not changing the ethanol price for juice and B-heavy route for 2024-25, the diversion of sugar into ethanol appeared to be non-rewarding [2]. According to Triveni, due to fixed sugar prices, their factories shifted to producing C-heavy molasses instead of B-heavy one. The result was lower distillery profit, but higher company profit [4].

III. Methodology

[A] Data and sources

We use the latest full season, sugar season (SS) 2024-25 and FY2025 (April 2024 to March 2025). All values come from the documents in the reference list. Cane is measured in lakh tonnes (1 lakh = 100,000) and money in rupees crore (1 crore = 10 million).

Table I: Input data and sources

Item	BCML	Triveni	Source type
Cane crushed, SS 2024-25 (lakh t)	99.16	81.90	Primary [3][4]
Gross sugar recovery (%)	11.28	10.80	Primary / secondary [3][4][6]
Avg. sugar realisation, FY25 (Rs/kg)	39.06	39.22	Primary [2][4]
Syrup-ethanol price, ESY 2024-25 (Rs/L)	65.61	65.61	Primary quoting govt. [2]
Ethanol yield, syrup route (L per t cane)	79.0	79.0*	Derived from [2]
Distillery capacity (KL per day)	1,050	860	Primary [2]; secondary [5]
Operating days assumed	330	330	Assumption
Output of non-syrup routes, FY25 (million L)	153.0	200.1	Primary [2][4]
Spare distillery capacity H (million L)	193.5	83.7	Calculated

The ethanol yield of 79.0 litres per ton is based on BCML's numbers from FY25 – 8.37 crore litres (83.7 million litres) of syrup-route ethanol produced from 105.91 lakh quintals (1.059 million tonnes) of cane. *Triveni's number is not known, so we assume the same technical yield – which is the least reliable input in our model, and which will be tested in Section IV. The non-syrup ethanol of BCML is the sum of ethanol sales of BCML from B-heavy, C-heavy, and grain routes, along with ENA and others (8.08 + 1.78 + 2.50 + 2.94 crore litres). The alcohol of Triveni is the total FY25 alcohol production (200,083 kilolitres), as there is no syrup route.

Spare capacity is the nameplate capacity (KLPD x 330 days) minus the ethanol that is already being produced on other routes: for BCML 346.5 – 153.0 = 193.5 million litres, and for Triveni 283.8 – 200.1 = 83.7 million litres. We use 330 day years as our assumption, as operating days are not given in the filing.

[B] Mathematical formulation

We follow the seven steps in the reference study. Step 1, the decision variables, are x , the cane (lakh tonnes) used on the sugar route, and y , the cane (lakh tonnes) diverted to the syrup-ethanol route. Step 2, the objective, is gross revenue in Rs crore:

$$\text{Maximise } Z = a x + b y$$

Here $a = \text{gross recovery} \times 10 \times \text{sugar price} / 100$, and $b = \text{ethanol yield} \times \text{ethanol price} / 100$. Dividing by 100 converts Rs per tonne into Rs crore per lakh tonnes. Step 3, the constraints, are the cane limit and the spare distillery capacity:

$$x + y \leq S \text{ (cane limit)}$$

$$y \leq H / 7.9 \text{ (distillery limit)}$$

$$x \geq 0, y \geq 0$$

S is the cane crushed in the season. In the second constraint, H is spare capacity in million litres and 7.9 million litres is the ethanol made from one lakh tonnes of cane (79.0 L/t x 100,000 t). Gross revenue is used because we have no verified conversion cost per route; cane cost is the same on both routes, so it does not change which route ranks higher.

Table II: Calculated model coefficients

Coefficient	BCML	Triveni
Sugar revenue per tonne of cane (Rs)	4,406	4,235
Ethanol revenue per tonne of cane (Rs)	5,183	5,183
a (Rs crore per lakh t, sugar route)	44.06	42.35
b (Rs crore per lakh t, ethanol route)	51.83	51.83
S (lakh t)	99.16	81.90
Max. ethanol cane $H/7.9$ (lakh t)	24.49	10.60

[C] Solution method

Steps 4 to 7: we draw both constraints on one graph (Figures I and II), shade the feasible region, find its corner points and put each corner into Z. The maximum of an LP always lies at a corner. As a check, we also solved both problems with the linprog function (HiGHS solver) of SciPy [7]; it gave the same answers as the corner-point test. We then repeated the test for lower ethanol prices to see when the best plan changes.

IV. Results and Discussion

[A] Results

Table III shows the corner-point test. For both companies the best point is C, where the cane limit and the distillery limit are both binding: the mill diverts as much cane to ethanol as its spare distillery allows, and the remaining cane goes to sugar.

Table III: Corner point test (Z in Rs crore)

Point	BCML (x, y)	BCML Z	Triveni (x, y)	Triveni Z	
A	(0, 0)	0	(0, 0)	0	
B	(99.16, 0)	4,369.0	(81.90, 0)	3,468.7	
C	(74.67, 24.49)	4,559.3	(71.30, 10.60)	3,569.2	Best
D	(0, 24.49)	1,269.6	(0, 10.60)	549.3	

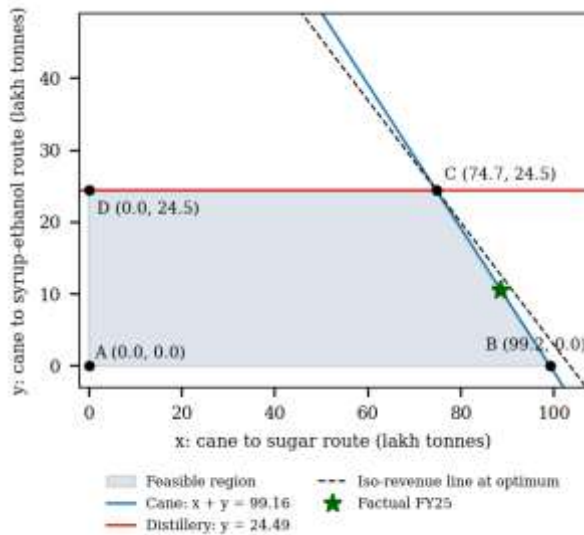


Figure I: Feasible region and corner points, BCML

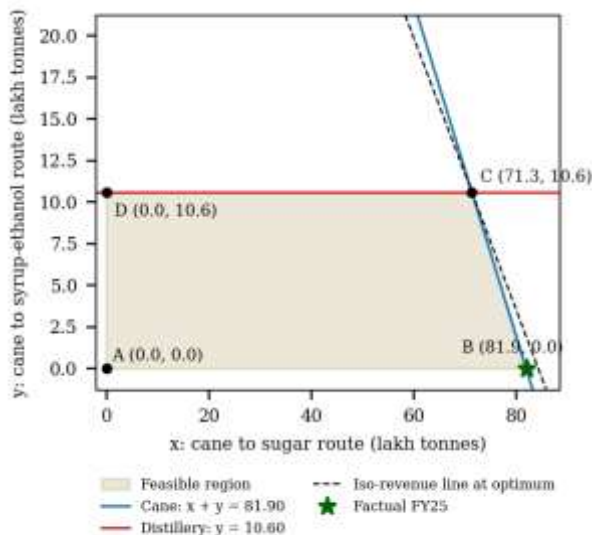


Figure II: Feasible region and corner points, Triveni

Table IV compares the factual plan with the optimal plan, as Table 3 of the reference study does. For BCML the factual plan sends 10.7% of cane (10.61 lakh tonnes) to syrup ethanol [3]; the model suggests 24.7%. For Triveni the factual plan has no syrup route in the filings, and the model suggests 12.9% of cane.

Table IV: Factual versus optimal plan

Company / plan	x (lakh t)	y (lakh t)	Z (Rs cr)	Change
BCML factual	88.55	10.61	4,451.4	-
BCML optimal	74.67	24.49	4,559.3	+107.9 (+2.4%)
Triveni factual	81.90	0.00	3,468.7	-
Triveni optimal	71.30	10.60	3,569.2	+100.4 (+2.9%)

The solver's dual values give a simple reading. At the optimum, one extra lakh tonne of cane is worth about Rs 44.06 crore (BCML) or Rs 42.35 crore (Triveni), because extra cane goes to sugar. One extra million litres of spare distillery

capacity is worth about Rs 0.98 crore at BCML and Rs 1.20 crore at Triveni, that is about Rs 9.8 and Rs 12.0 per litre. Triveni's distillery is the tighter limit, so each unit of extra capacity is worth more to it.

[B] Sensitivity to the ethanol price

The ethanol route wins only while its revenue per tonne of cane exceeds the sugar route. Setting $79.0 \times \text{price} = \text{sugar revenue per tonne}$ gives break-even ethanol prices of Rs 55.77 per litre for BCML and Rs 53.61 per litre for Triveni. The government syrup price of Rs 65.61 is about 18% and 22% above these levels. Equivalently, sugar would beat ethanol if the sugar price rose above Rs 45.95 per kg (BCML) or Rs 47.99 per kg (Triveni).

Table V: Optimal plan at different ethanol prices

Ethanol price (Rs/L)	Best plan	BCML Z (Rs cr)	Triveni Z (Rs cr)
65.61 (government)	Point C	4,559.3	3,569.2
58.00	Point C	4,412.1	3,505.5
53.00	Point B (all sugar)	4,369.0	3,468.7

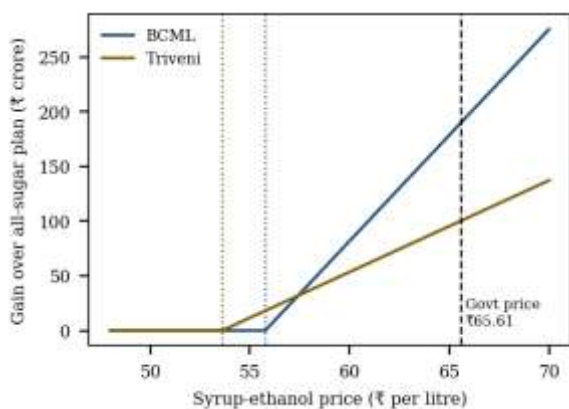


Figure III: Gain from diverting cane to ethanol at different ethanol prices

At Rs 58 the best plan is still point C but the gain over all-sugar is small. At Rs 53 the corner flips to B and both mills should send all cane to sugar. This is the same type of result as in the reference study, where the answer moved to an extreme corner (15 cabinets, 0 tables), but here the flip is caused by a price, so the model also tells us when to change plan.

[C] Critical analysis

The strength of the method is that every number can be traced to a filing and every step can be redone in Excel Solver or Python. The graph also shows why the answer is point C: it is the only corner where both limits bind, so the mill cannot gain by moving either way.

A simple graphically illustrated LP problem from a previous study, initially developed for the furniture workshop, was applied here to the two listed sugar firms. Using the FY2024-25 figures, the optimal strategy for both would involve utilising all available distillery excess capacity for the production of ethanol from the cane syrup and processing the rest of the cane for sugar. This model predicts that the gain in gross revenue for BCML would be approximately Rs 108 crore (+2.4%), while that of Triveni would be Rs 100 crore (+2.9%) compared to the factual plans. The advantage in going for ethanol is limited to as long as the price of ethanol remains above approximately Rs 56 and Rs 54 per litre, respectively.

As the costs, by-products, and policy issues are not accounted for, the conclusions should be seen as an illustrative example of decision-making in OR terms.

[D] Extensions

A more improved model would incorporate net profit and the known cost per route, include the additional route which is B-intensive as a third variable (which could be solved using Excel Solver or simplex method), include the minimum sugar to meet the domestic quota, and also use more than one season.

V. Conclusion

A simple graphically illustrated LP problem from a previous study, initially developed for the furniture workshop, was applied here to the two listed sugar firms. Using the FY2024-25 figures, the optimal strategy for both would involve utilising all available distillery excess capacity for the production of ethanol from the cane syrup and processing the rest of the cane for sugar. This model predicts that the gain in gross revenue for BCML would be approximately Rs 108 crore (+2.4%), while that of Triveni would be Rs 100 crore (+2.9%) compared to the factual plans. The advantage in going for ethanol is limited to as long as the price of ethanol remains above approximately Rs 56 and Rs 54 per litre, respectively.

As the costs, by-products, and policy issues are not accounted for, the conclusions should be seen as an illustrative example of decision-making in OR terms.

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