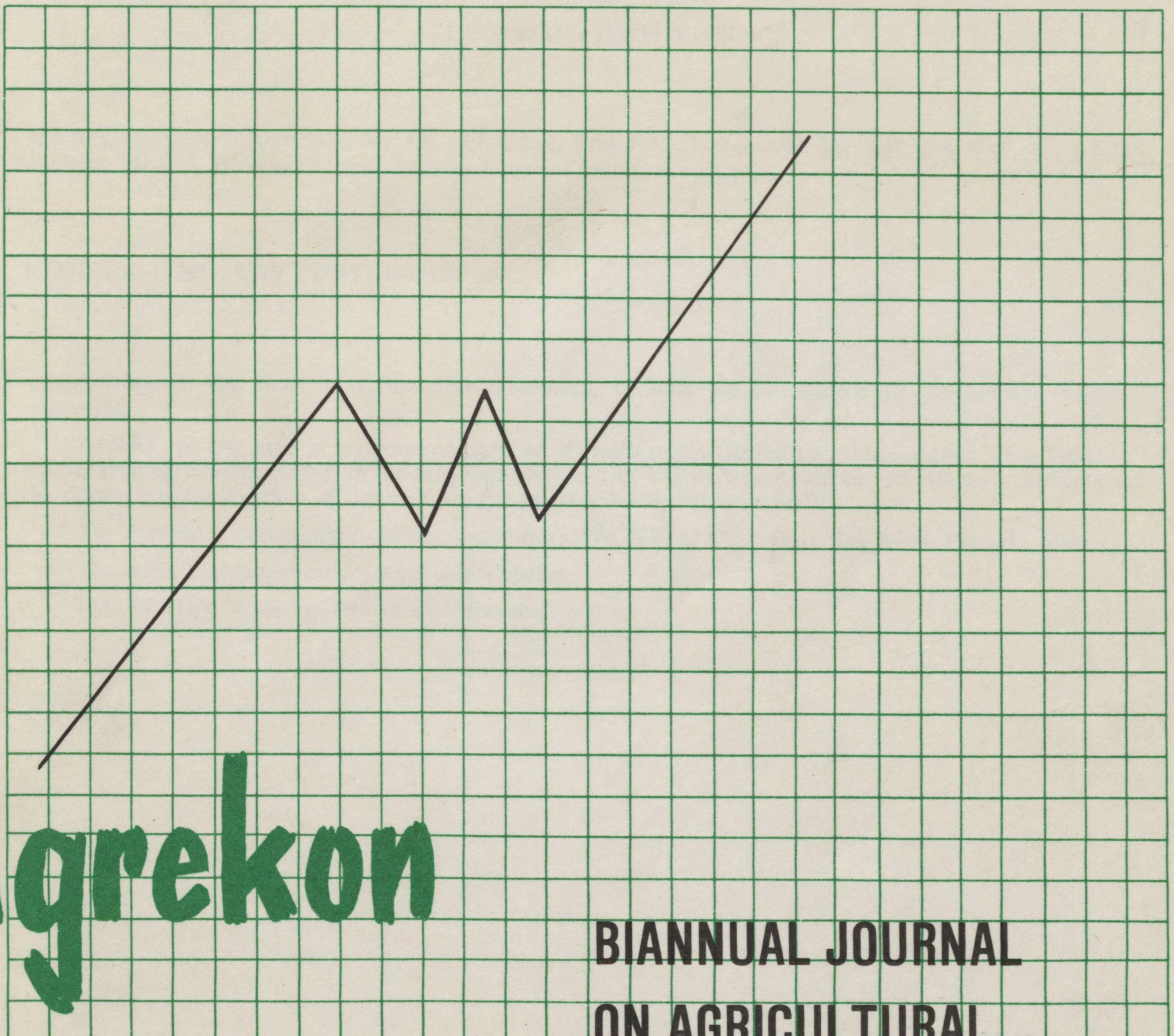
Vol. 22 No. 1
APRIL 1983

Price 50c
(48c + 2c GST)



Agrekon

BIANNUAL JOURNAL ON AGRICULTURAL ECONOMICS

Issued by the Department of Agriculture, Pretoria

PLANT SIZES AND LOCATIONS IN THE SOUTH AFRICAN SUGAR INDUSTRY

by G.K. CHADWICK
and W.L. NIEUWOUDT*

1. INTRODUCTION

In order to determine the optimum location, number and sizes of raw sugar mills in South Africa, it is necessary to consider both cane transport and milling costs. In the last decade the trend in sugar milling has been towards larger mills. Smaller mills have been closed down and the existing mills expanded. The economic soundness of this trend was tested with a plant size/location model, using a non-linear technique, separable programming.

Because cane transport is partially subsidised, this could lead to the development of huge mills where cane is transported over long distances to the mill. The millers would consider milling costs only when deciding on the location and size of the mill, since they would have no incentive to economise on transport costs. The plant size/location model used in this study determined the optimum transport network of sugar-cane supplies to mills, optimum locations and sizes of mills and the optimum distribution pattern of raw and refined sugar which would minimise the sum of cane transport, sugar transport and milling costs, allowing for economies of scale in milling costs.

With regard to the policy implications of plant size/location models, Stollsteimer (1963) comments:

"Solving this problem is important to the firm, both from the standpoint of maximizing profits and as a guide for investment in plant and equipment. Answers to similar questions when asked with respect to an industry are important both to the individual firms comprising the industry and to society in general, as they provide a partial measure of the economic efficiency of the industry."

2. DESCRIPTION OF THE PLANT SIZE/ LOCATION MODEL

Where economies of scale exist in processing, transportation and processing costs are inversely related. The greater the number of plants, the smaller they are and therefore the higher processing costs. Transportation costs, however, are lower because distance from supply areas to processing plants is reduced. This is illustrated in Figure 1.

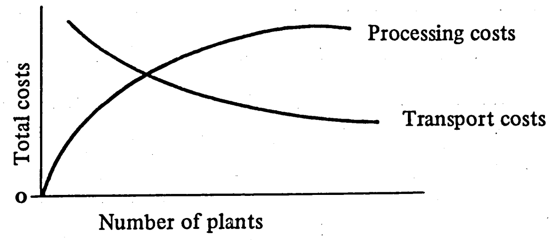


FIG. 1 - Relationship between number of plants, processing costs and transport costs

Presumably, therefore, there is an optimum number of plants where the sum of transport costs and milling costs is minimised.

The plant size/location model used is in fact an extension of the normal linear programming transhipment model. The major difference is that in addition to linear transport costs of raw and processed products, non-linear processing costs are also considered. Where economies of scale have to be considered, the non-linear, separable programming technique has several advantages over other methods. The chief advantage is that both transport and milling costs are simultaneously minimised in the model. It is therefore simpler and more precise than a model using an iterative procedure such as the King-Logan model (King and Logan, 1964).

The separable programme handles non-linear functions by segmenting the function into linear steps (Baritelle and Holland, 1975).

The separable programming model of the sugar industry considered transport of sugar-cane, processing of sugar-cane and transport of raw and refined sugar. Sugar-cane transport from 130 different production areas to 17 raw sugar mills was studied. Transport and processing of sugar-cane were expressed in terms of tons of sucrose at mills. Sucrose is converted to raw sugar at the mill. Raw sugar is either refined, exported or sold locally as brown sugar. Sugar transport costs were calculated for raw sugar, from mills to export markets or refineries, for brown sugar from mills to local markets and for refined sugar from refineries to local markets. Raw sugar is converted to refined sugar at seven refineries.

A simplified example of the matrix incorporated in the model is illustrated in Table 1. Cane-producing areas are depicted as S1 - S5, D1, D2 and D3 are demand regions for brown sugar, L1 and L2 are two potential mill locations, R1 and R2 are refineries and the milling cost function has

* G.K. Chadwick is a master's student and W.L. Nieuwoudt is an Associate Professor at the University of Natal. Work was carried out in the Agricultural Policy Research Unit at the University of Natal; the Unit receives financial support from the HSRC. Opinions expressed are those of the authors and do not necessarily reflect those of the HSRC or the University of Natal

TABLE 1 - Separable Programming Matrix of the South African Sugar Industry

	S1 L1	S2 L1	S3 L1	S4 L1	S5 L1	S1 L2	S2 L2	S3 L2	S4 L2	S5 L2	L11	L12	L13	L21	L22	L23	L1 D1	L1 D2	L1 D3	L2 D1	L2 D2	L2 D3	L1 R1	L1 R2	L2 R1	L2 R2	R1 W1	R1 W2	R2 W1	R2 W2	RHS
C	30	40	60	10	18	21	32	63	19	12	5000	4000	3000	5000	4000	3000	40	80	50	32	29	61	9	15	12	8	36	48	10	32	
R1	1					1																									4000
R2		1					1																								6000
R3			1					1																							8000
R4				1					1																						12000
R5					1					1																					9000
R6	-1	-1	-1	-1	-1						1000	1000	1000																		0
R7						-1	-1	-1	-1	-1				1000	1000	1000															0
R8											-1000	-1000	-1000				1,16	1,16	1,16				1,16	1,16							0
R9														-1000	-1000	-1000				1,15	1,15	1,15			1,15	1,15					0
R10																							-1		-1		1,08	1,08			0
R11																								-1		-1			1,08	1,08	0
R12																	1			1											10000
R13																		1			1										8000
R14																			1			1									6000
R15																							1		1						8000
R16																								1		1					6000
R17																											1		1		6000
R18																												1		1	4000

Source: Derived from Baritelle and Holland, 1975, pp. 73-82

three segments: 1, 2 and 3. The refineries supply the following demand regions with white sugar: W1 and W2. Costs of activities are reflected in the C row. The costs of activities S1L1 to S5L2 relflect the costs of transporting one ton of sucrose to a mill. The costs of L11 are the costs of processing the initial 1 000 tons of sucrose, L12 the costs of processing an additional 1 000 tons of sucrose, and so on. The costs of L1D1 to L2R2 are the costs of transporting one ton of raw sugar from the mill to its destination, and the costs of R1W1 - R2W2 are the costs of transporting one ton of white sugar from the refinery to the market.

The rows R1 to R5 are restraints on the amount of sucrose supplied by five production areas. The maximum amount each area may supply is depicted in the RHS column. R6 and R7 are transfer rows, transferring sucrose from supply areas to mills. Transfer rows R8 and R9 transfer raw sugar from mills to brown sugar demand regions and refineries. The conversion ratios of the mills are also reflected in these rows. Mill L1 produces one ton of raw sugar from 1,16 tons of sucrose, whereas Mill L2 produces one ton of raw sugar from only 1,15 tons of sucrose. R10 and R11 are refinery transfer rows. One ton of refined sugar is produced from 1,08 tons of raw sugar.

R12 - R14 are restraints on amount of brown sugar demanded at regions D1, D2 and D3 respectively. The amounts are shown in the RHS column. R15 is a restraint on the maximum amount of raw sugar that refinary R1 can process in a year. R16 restrains refinary R2. The demand for white sugar at regions W1 and W2 is restrained by rows R17 and R18 respectively.

The solution to the model gives the optimum mill size, optimum allocation pattern of sugar-cane supplies and optimum distribution pattern of sugar that simultaneously minimises the sum of milling, sugar-cane transport and sugar transport costs.

3. ALTERNATIVE MODEL SIMULATIONS

Three different versions of the model described above were used:

Model I. Only existing mill locations were considered. The amount of sucrose processed at each mill in a season was limited to that mill's maximum capacity. The mill's maximum capacity is reflected in the maximum amount of sucrose that a mill can process in a season of forty weeks.

Model II. Existing mill locations were considered. These are illustrated in Map 1. In this model there were no restraints on mill capacity.

Model III. Fifty-two possible mill locations were included in this model. These were spread over the whole sugar industry. No restraints on milling capacities were included.

Model I represents the short-term situation. Mills cannot expand their capacity but can increase their processing levels up to their maximum capacities. It is assumed that farmers are free to supply any mill. In the long term mills can expand or close down. This was simulated in model II, except that no new mill locations were considered. In model III new mills can be built and old mills closed down. This model was large, with 5 729 columns and 408 rows. Owing to its size some difficulty was encountered in arriving at a stable solution.

4. DERIVATION OF MILLING COST CURVES

Milling cost curves were derived from actual milling costs incurred in the 1977/78, 1978/79 and 1979/80 seasons for mills of different sizes. The purpose was to determine to what extent larger mills are more cost-efficient than smaller mills. The data were therefore subjected to regression analyses in an attempt to derive an economies of scale curve for sugar milling.

According to the following functions, a significant fall in average cost occurs with an increase in plant size. Significant economies of scale therefore occur. However, there is a danger in extrapolating data outside the existing range of observations. In such extrapolations, cost functions published for the Australian sugar industry (Ryland 1969) and the Mauritian sugar industry (Paturau 1978) were also considered in the model.

$$Y = 109{,}2 - 0{,}0001704\,x \quad R^2 = 0{,}82 \qquad (1)$$
$$(t = 7{,}7)$$

$$Y = 112{,}1 - 0{,}000251\,x1 + 0{,}346\,x^2\,(10^{-9})\ R^2 = 0{,}83 \qquad (2)$$
$$(t = 2{,}5) \qquad (t = 0{,}8)$$

$$Y = 76{,}9 - 0{,}8714\,(10^{-8})\ R^2 = 0{,}67 \qquad (3)$$
$$x$$
$$(t = 5{,}2)$$

An impression of cost functions incorporated in the model can be gained from Figure 2. In the case of the linear function (A), it was assumed that there were no longer economies of scale in mills processing more than 230 000 tons of sucrose per season. This is represented by the Curve C in Figure 2. The adjusted quadratic cost curve is represented by the Curve D in Figure 2. The quadratic function reaches its lowest point at a mill size of 350 000 tons of sucrose processed per season. In the Curve D it was assumed that there are no diseconomies of scale, but that costs per ton of sucrose processed remain constant for mills larger than 350 000 tons. The quadratic cost curve therefore gives a lower limit to the costs of large mills. Both the linear and the quadratic cost curves were used in all three models.

5. RESULTS OF MODELS

The results of models I and II are shown in Table 2. The mill locations and sizes chosen in the models are included. It appears from Table 2 that the present trend towards fewer and larger mills is in the best interests of the industry and that this trend should continue. Economies of scale in milling seem to outweigh the higher transport costs incurred by large mills. In model I, using both linear and quadratic curves, Glendale Mill is closed down and its present sucrose supplies diverted elsewhere. With a processing level of only 37 956 tons of sucrose per season, Glendale is the smallest mill in the industry.

In model II, where there is no limit on mill capacities, the trend towards fewer mills is even more marked. In model II (linear cost curve), where economies of scale are not pronounced, twelve mills are chosen, with an average mill size of 227 000 tons of sucrose processed per season.

Economies of scale are accentuated in the quadratic cost curve and only ten mills with an average size of 272 404 tons of sucrose processed per season were chosen in that model.

Fourteen mills were selected in the solution to model III (linear cost curve). Fewer mills were again chosen when the quadratic cost curve was used, namely 12 mills. The locations and sizes of mills selected in model III can be seen in Table 3. Model III has slightly more mills than model II. In model III mills were relocated to minimise sugar-cane transport costs. Therefore, although

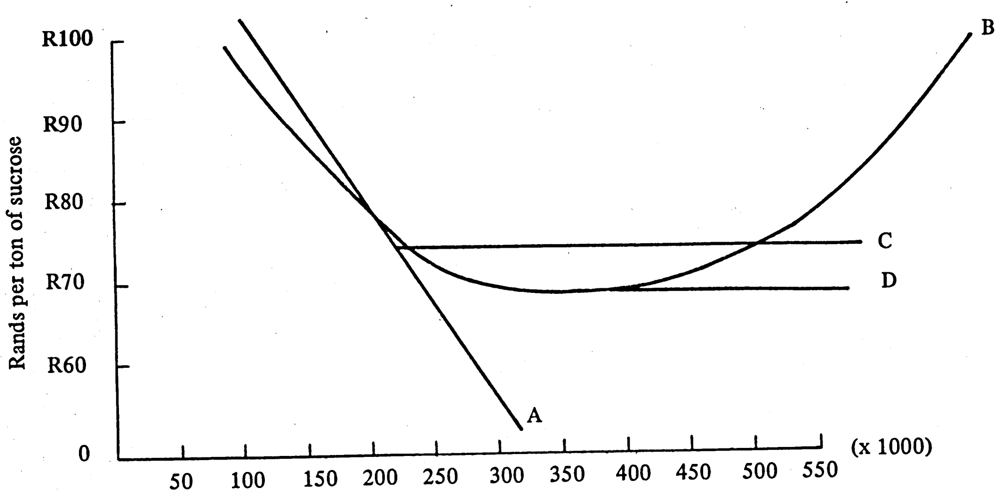
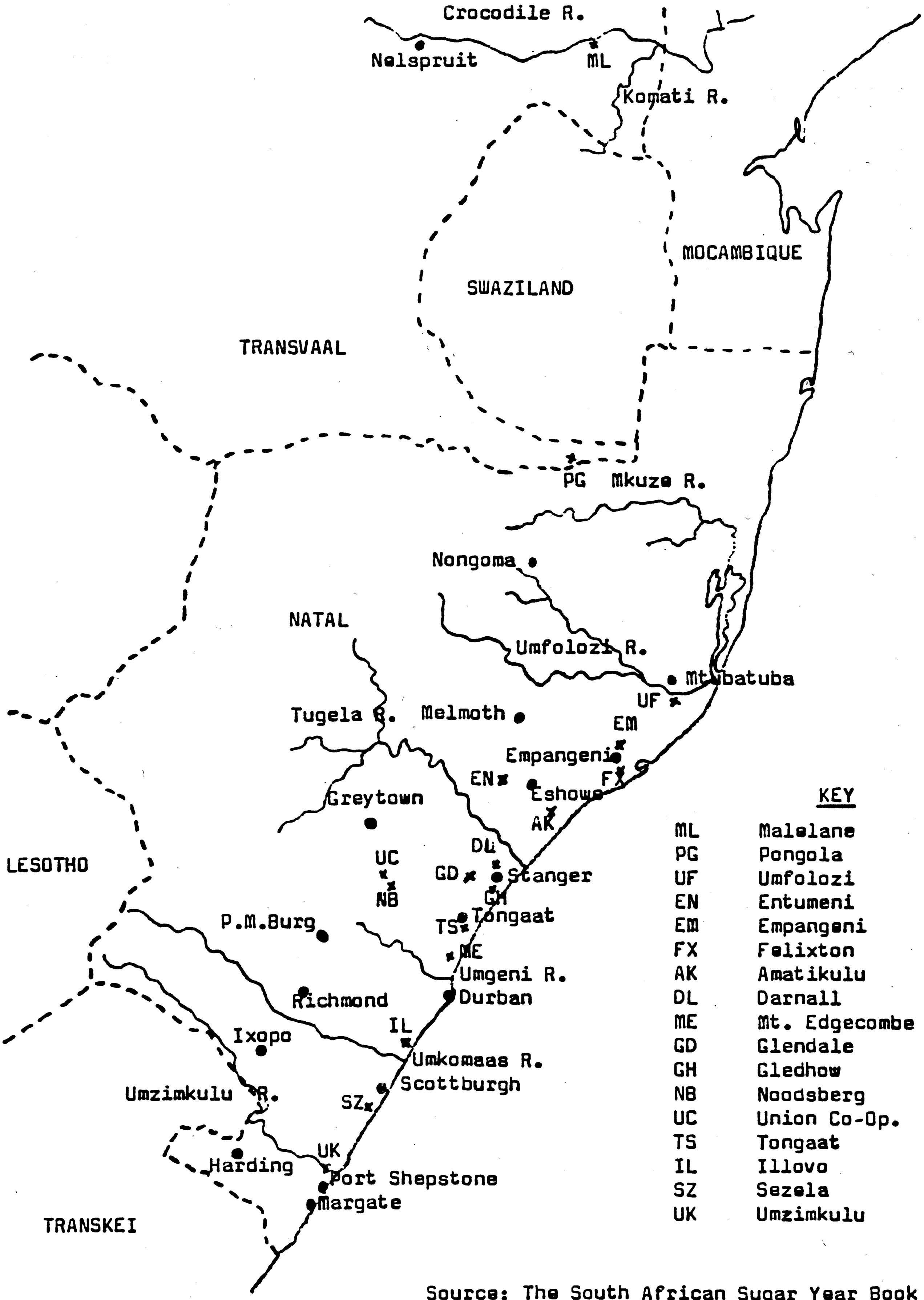


FIG. 2 - Economies of scale curves : Milling costs

MAP 1.—THE LOCATION OF SUGAR MILLS IN THE SOUTH AFRICAN SUGAR INDUSTRY



Source: The South African Sugar Year Book No. 50, 1979/1980 Edition

TABLE 2 - Mill Locations and Sizes Chosen in Plant Size/Location Models I and II (Tons of sucrose processed per season)

Mill location	Present level	Linear cost curve Model I	Linear cost curve Model II	Quadratic cost curve Model I	Quadratic cost curve Model II
Malelane	194 425	194 425	194 425	194 425	194 425
Pongola	108 687	118 179	108 687	118 179	108 687
Umfolozi	158 999	179 440	230 000	179 440	133 911
Entumeni	50 533	50 046	199 579	46 335	-
Empangeni	156 295	156 438	-	156 438	345 000
Felixton	137 445	112 296	230 000	122 872	-
Amatikulu	270 350	282 898	230 000	282 898	345 000
Darnall	209 643	209 643	-	209 643	-
Mt. Edgecombe	157 242	160 854	230 000	160 854	-
Glendale	37 956	-	-	-	-
Gledhow	216 613	224 357	330 064	224 357	428 546
Noodsberg	175 709	196 587	246 877	196 587	345 000
Union Co-op.	73 776	42 084	-	36 672	-
Tongaat	281 959	281 959	230 000	281 959	345 000
Illovo	108 085	147 290	264 407	123 657	-
Sezela	253 373	230 000	-	257 164	345 000
Umzimkulu	132 949	137 542	230 000	132 559	133 469
Average:	**160 237**	**170 252**	**227 000**	**170 252**	**272 404**

TABLE 3 - Mill Locations and Sizes Chosen in Plant Size/Location Model III (Tons of sucrose processed per season)

Mill location	Quadratic cost curve	Linear cost curve
Malelane	194 425	194 425
Pongola	108 687	108 687
Umfolozi	61 612	216 102
Melmoth	47 721	47 721
Entumeni	-	87 153
Mevamhlope	-	230 000
Empangeni	345 022	-
Amatikulu	345 000	230 000
Kearsney	-	230 000
Gledhow	345 000	273 915
Chaka's Kraal	416 249	-
Tongaat	-	273 532
Glenside	293 216	230 000
Eston	159 706	227 940
Renishaw	306 631	-
Sezela	-	242 005
Paddock	91 770	132 559
Average:	**227 000**	**194 574**

milling costs in model III are higher than milling costs in model II, sugar-cane transport costs are considerably lower and the sum of sugar-cane transport, sugar transport and milling costs is a minimum.

The significant information provided by model III is the general pattern of mill locations and sizes rather than actual mill locations chosen. In model III (quadratic cost curve), two mills were chosen in the Eastern Transvaal, four were chosen in Zululand, two on the North Coast, one in the Midlands, one in the Southern Midlands and two on the South Coast. The results using the linear cost curve are very similar except that there is an additional mill in Zululand and another on the North Coast.

Significant mill locations in model III are Eston and Melmoth. At present, cane grown in the Southern Midlands is transported to the Illovo Mill on the South Coast or the Mt. Edgecombe Mill on the North Coast. Cane transport costs would be greatly reduced if a mill was built at Eston in the Southern Midlands to process this cane.

Cane grown at Melmoth has to be transported to the Amatikulu Mill, over eighty kilometers away. If growers were forced to pay the full transport costs of cane to the mill, then the Melmoth growers would be seriously prejudiced and many could be forced out of cane production. These growers could be prompted to build a co-operative mill at Melmoth. However, with only 47 721 tons of sucrose available per season from the Melmoth area, the mill would be small, with high milling costs. The average milling cost would be approximately R101,80 per ton of sucrose. At 1981/82 season prices, the price per ton of raw sugar prevailing at the mills would have to be at least R313,70 for Melmoth growers to receive their full return on capital and management remuneration, if a co-operative mill were built at Melmoth.

The average milling costs of each mill in models I and II are illustrated in Table 4. If Tables 2 and 4 are compared, it becomes apparent that larger mills are far more cost-effective than smaller mills. The average milling costs drop from R81,00 to R76,00 per ton of sucrose (linear cost curve) and from R79,70 to R71,40 per ton of sucrose (quadratic cost curve) when the number of mills is reduced and their average size increased. The

TABLE 4 - Average Milling Costs per Mill in Models I and II (per ton of sucrose processed)

Raw sugar mills	Model I Linear cost curve	Model I Quadratic cost curve	Model II Linear cost curve	Model II Quadratic cost curve
Malelane	R79,30	R79,20	R79,30	R79,20
Pongola	R90,90	R89,70	R92,40	R91,20
Umfolozi	R81,80	R81,20	R74,70	R86,90
Entumeni	R100,90	R102,00	R78,60	-
Empangeni	R84,90	83,90	-	R67,80
Felixton	R91,90	R88,80	R74,70	-
Amatikulu	R74,70	R71,20	R74,70	R67,80
Darnall	R80,10	R77,60	-	-
Mt. Edgecombe	R84,40	R83,90	R74,70	-
Gledhow	R75,30	R76,20	R74,70	R67,10
Noodsberg	R79,00	R79,00	R74,70	R67,80
Union Go-op.	R102,00	R104,10	-	-
Tongaat	R74,70	R71,30	R74,70	R67,80
Illovo	R86,00	R88,70	R74,70	-
Sezela	R74,70	R73,00	-	R67,80
Umzimkulu	R87,50	R87,00	R74,70	R87,00
Average:	**R81,00**	**R79,70**	**R76,00**	**R71,30**

average milling costs depicted in Table 4 were determined using cost curves described earlier and do not take into account the particular circumstances at each mill. For example, the average milling cost at the Union Co-op. Mill is likely to be lower than the cost shown in Table 3 because the mill lowers its fixed costs by processing wattle bark in the off season.

Referring to Tables 2, 3 and 4, it is apparent that mill sizes tend to be chosen at the point where there are no longer economies of scale. In models employing the quadratic cost curve, the most popular mill size is 345 000 tons of sucrose processed per season, whereas where the linear cost curve was used, 230 000 tons of sucrose processed per season was the predominant mill size. It would appear therefore that the optimum mill size for the industry lies between 230 000 and 345 000 tons of sucrose per season.

CONCLUSION

From the results presented, it appears that the present trend towards larger mills is economically sound. This involves the closure of a number of mills. In the short term, Glendale is closed down. In the long term, the number of mills is reduced to 12 (linear cost curve) and to only 10, using the quadratic cost curve.

Although the present trend is economically sound, it is important that this trend should not continue indefinitely because a point will be reached where economies of scale in sugar milling no longer offset increased cane transport costs. The optimum mill size in models employing the quadratic cost curve appears to be 345 000 tons of sucrose processed per season. On the other hand, if a linear cost curve is used, 230 000 tons of sucrose processed per season appears to be the optimum.

When the number of mills is reduced from 17 to 12 (linear cost curve), the average milling cost per ton of sucrose is reduced from R81,00 to R76,00. In models using the quadratic cost curve, 7 mills were closed down, reducing the average milling cost from R79,70 to R71,30 per ton of sucrose.

In order to ensure the sound economic development of the sugar industry, it is important that rationalisation in sugar milling should continue.

REFERENCES

1) BARITELLE, J.L. & HOLLAND, D.W. Optimum Plant Size and Location: A Case for Separable Programming. Agricultural Economics Research, Vol. 27, October 1975.
2) KING, G.A. & LOGAN, S.H. Optimum Location, Number and Size of Processing Plants with Raw Products and Final Product Shipments. Journal of Farm Economics, Vol. 45, February 1964.
3) PATURAU, J.M. Les Economies D'Echelle Dans L'Industrie Sucrière. Paper presented at the 1978 Congress of the Association Rèunionnaise pour le Developpement de la Technologie Agricole. et Sucrière, 1978.
4) RYLAND, G.T. Economies of Scale in Sugar Milling. Proceedings of the Queensland Society of Sugar Cane Technologists, 1969.
5) STOLLSTEIMER, J.F. A Working Model for Plant Numbers and Locations. Journal of Farm Economics, Vol. 45, August 1963.
6) The South African Sugar Year Book, No. 50, 1979-1980 edition, 1980.