SPATIAL REORGANIZATION AND THE BARBADOS SUGAR INDUSTRY

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ABSTRACT

This study examines some aspects of spatial reorganization in the Sugar Industry of Barbados. More specifically, it focuses on location allocation problems for sugar cane in both short term and future situations. The problems relate to the method of allocating canes between farms and factories, and to the reorganization of the factory system. The objective of the thesis is to create an efficient method of sugar cane allocation, and to arrive at location decisions for a reduced number of factories given increased efficiency in the industry as a desirable goal.

The methodology used is linear programming. This technique allows the utilization of scarce resources as effectively as possible, given the peculiar constraints of individual situations. Allocation solutions are found for the harvests of 1973 and 1974. The results yield valuable insights into the scheduling aspects of allocation, implications regarding locational advantage of the various estates and cane producing peasant farms, as well as a partial pricing structure for the industry.

From the allocation results the scope of the thesis develops to embrace the whole issue of centralization within a historical and contemporary context. Four factories are taken as the optimal number for an improved system and optimum locations are found for them as well as the resultant changed allocations.

The rationale for the thesis comes from the crucial importance of the sugar industry in the economy of the island with a contribution of over 50% of the value of all visible exports, from the sale of sugar and by products. More importantly the industry is currently going through a period of crisis and if massive reorganization in all facets of its structure is not undertaken then collapse seems inevitable in the very near future. The thesis therefore

suggests new approaches to some managerial aspects of reorganization, and the possible implications of any such changes for the entire Sugar Industry of Barbados.

ACKNOWLEDGEMENTS

I would like to express my thanks to the many people whose help was invaluable in the preparation of this thesis. Among these are the management and workers of the Barbados Sugar Producers Association for the use of their files and information, and the many cane farmers all over the island. Thanks is also extended to Mr. A. Brathwaite, Senior Economist, Ministry of Agriculture, Science and Technology. Field work was made possible through a grant from the Institute of Social and Economic Research, Memorial University of Newfoundland. Thanks are also due to Mrs. Brenda Spurrell, Memorial University for keypunching assistance, and to Dr. Maurice Scarlett for reading and commenting on the text. Finally I would like to offer sincere appreciation to my supervisor, Mr. Keith Storey, who always pointed me in the right direction, and for all his help and advice given freely and at all times.

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I. BACKGROUND TO THE STUDY

This study examines some of the organizational aspects of the Sugar Industry of Barbados. It is an industry which has always dominated the economy of the island, and also created a specific type of racial, social and political structure very much evident today. Since its introduction in the 1640's and the rapid development of the plantation system, sugar cane has maintained the leading role in the economic growth of Barbados. Today earnings from sugar bring into the island's economy approximately $30,000,000.00 (EC) yearly.[1] Besides direct foreign exchange revenue from sugar sales, usually to Britain, Canada and USA, there are many linkages into the rest of the economy through the creation of by - products and secondary uses for sugar.

A. The Setting

Barbados lies within the chain of Caribbean islands which span from North to South America. Its specific location is latitude 13.4°N and 59°37'W (Figure 1). It is a very small island of only one hundred and sixty six square miles with a population of 241,084 people.[2] The sugar cane which was not originally a native of the island was introduced from Brazil in 1637 and commercial production and manufacture of sugar began a few years later. In 1640 James Drax brought cattle mills and other processing equipment into the island and with the aid of Dutch capital and expertise the island soon developed a large viable industry. As early as 1667 all the arable land had been cleared of original vegetation, the early

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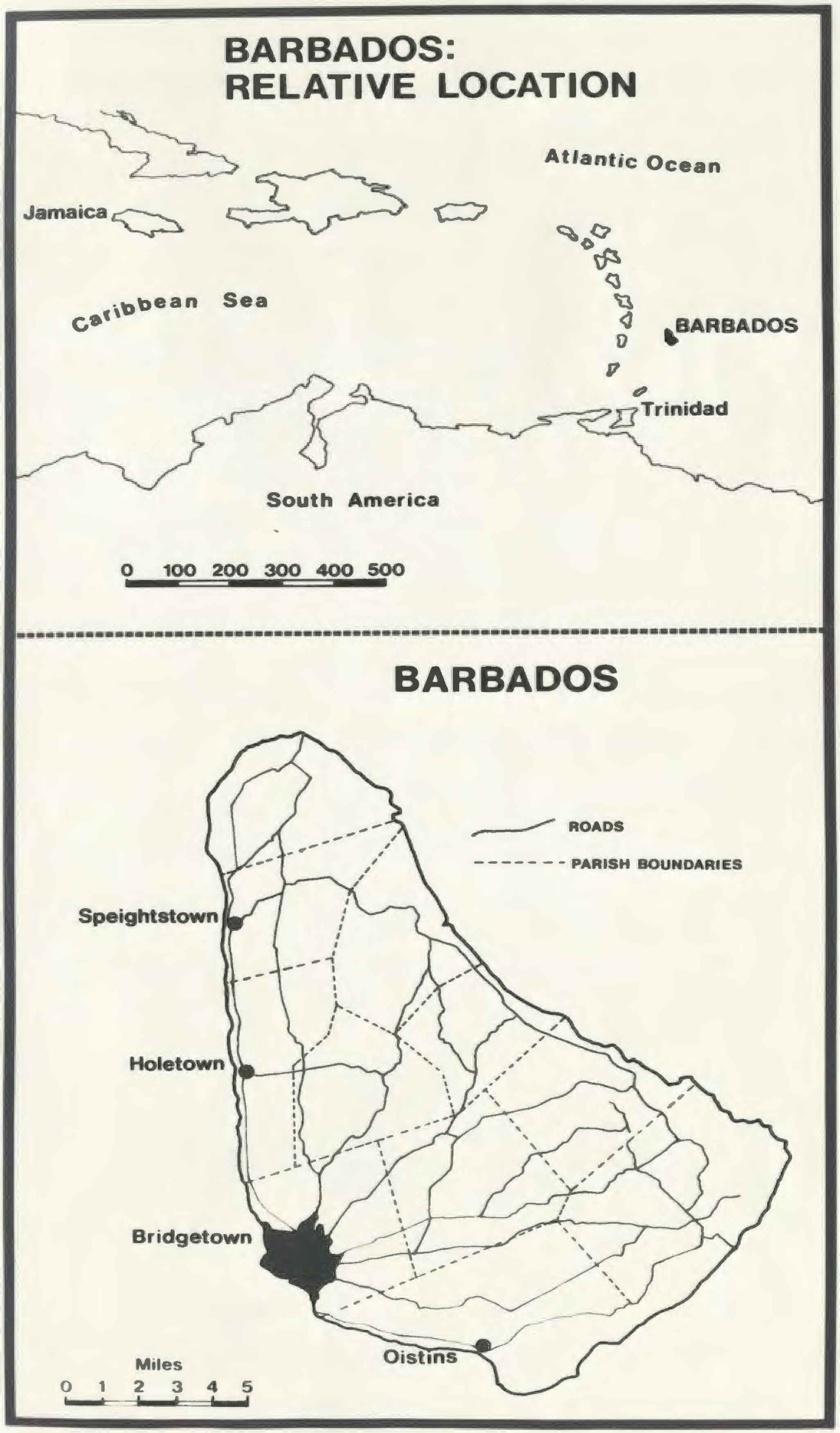
[1]Barbados Economic Survey, Barbados Government Printing Office, 1971, 8-9. All currency values are in Eastern Caribbean currency

[2]op. cit. 12.

Figure 1


BARBADOS:
RELATIVE LOCATION
Atlantic Ocean
Jamaica
Caribbean Sea
BARBADOS
Trinidad
South America
0 100 200 300 400 500
BARBADOS
ROADS
PARISH BOUNDARIES
Speightstown
Holetown
Bridgetown
Oistins
Miles
0 1 2 3 4 5

yeoman farmers were displaced and the plantation system firmly entrenched with its large farms, boiling houses and gangs of slave labour. Since then sugar and plantations have continuously dominated the destinites of the people of the island and still exert considerable influence today. Present day production is done on approximately 200 estates and 18,000 peasant farms, the latter combining sugar cane culture with other forms of economic activity.

The sugar cane crops make a much greater contribution to the economy of the island than just sugar sales. This is derived through by products and other linkages into the economy, as well as creating employment for much of the labour force. The most important by products at the moment are rum, which nets approximately $6,000,000.00 annually, and molasses $4,000,000.00.[1] The other product of importance is "Bagasse" the fibrous material left after the juice is extracted from the cane pith used mainly to fire the factory boilers, and as a base for animals feeds. With the recent development of the "Separation Process" new ranges of by products from sugar cane appear feasible. The new process removes the outer rind from the cane leaving the fibres undamaged. Two major products come from the new method. Compith is the main product and contains 70-80% of the cane stalks and 93% sucrose. After the sugar is extracted, Compith is then broken down into the component fibres and pith cells. These are then used in the manufacture of soft board, hard board, pulp and paper, animal feeds, and explosives. Comrind, the second important product, can be processed into laminated timber, core panels and plywood veneers.[2]

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[1] Barbados Economic Survey, op. cit., 7.

[2] Barbados Sugar Industry Review, 16, 1973 (June), 6-8.

The sugar Industry has traditionally held and still continues to hold the position as the largest single employer of labour (Table 1), accommodating over 15% of the work force, though at very low wage levels.

TABLE 1

Industrial Classification (1970 Census)

Industry	Male	Female	Total
Sugar	10,178	5,856	16,034
Other Agriculture	1,509	272	1,781
Mining, Quarrying, etc.	279	16	295
Manufacturing	6,839	4,398	11,237
Construction	10,450	287	10,737
Electricity, Water, Gas, etc.	1,008	80	1,088
Commerce	6,062	6,116	12,178
Transport, etc.	4,059	565	4,624
Services - Government	5,088	4,794	9,882
Services - Other	5,498	10,315	15,813
TOTAL	50,970	32,699	83,669

Source: unpublished data, Barbados Census, 1970, Government Statistical Service

Recently there has been rapid growth in the other sectors of the economy as for example tourism, construction, and the manufacture of consumer goods. However the Distribution sector producing 20.3% of total GDP and sugar 11.4%, are still the two major contributors to economic expansion.[1]

[1] Barbados Economic Survey, op. cit. 19.

Equally important is the fact that the island's largest and most important resource, apart from its people, is its agricultural land and sugar has proved to be the most satisfactory crop so far, given our climatic and agronomic conditions. In a recent proposal for continuing sugar cane development the Ministry of Agriculture set a target figure of 180,000 tons of sugar annually by 1980, thereby demonstrating a basic faith in its continuing important contribution to development.[1]

B. Present Problems

Recently however the industry has been going through one of its periodic phases of falling production due to a combination of adverse factors facing it. This is readily reflected in production trends in the last five years (Figure 2). Since 1968 there has been a marked decline in tonnage of sugar produced, output decreasing by 90,000 tons from 1967 to 1972. A contributory factor is the yield of cane per acre of arable land which has declined rapidly (Figure 3). Decrease is also reflected in a lower tonnage of sugar per acre, output varying from 4.1 tons in 1963 and 1965 to 2.8 tons in 1971.[2] The latter is a result of declining tonnage per acre, and also a lower sucrose content in the canes in recent years.

Many reasons can be cited to explain the changes. In his presidential address 1953 to the International Society of Sugar Cane Technologists Sir John Saint identified six variables as being the key factors which control the output of sugar in Barbados. These were, acreage under cane,

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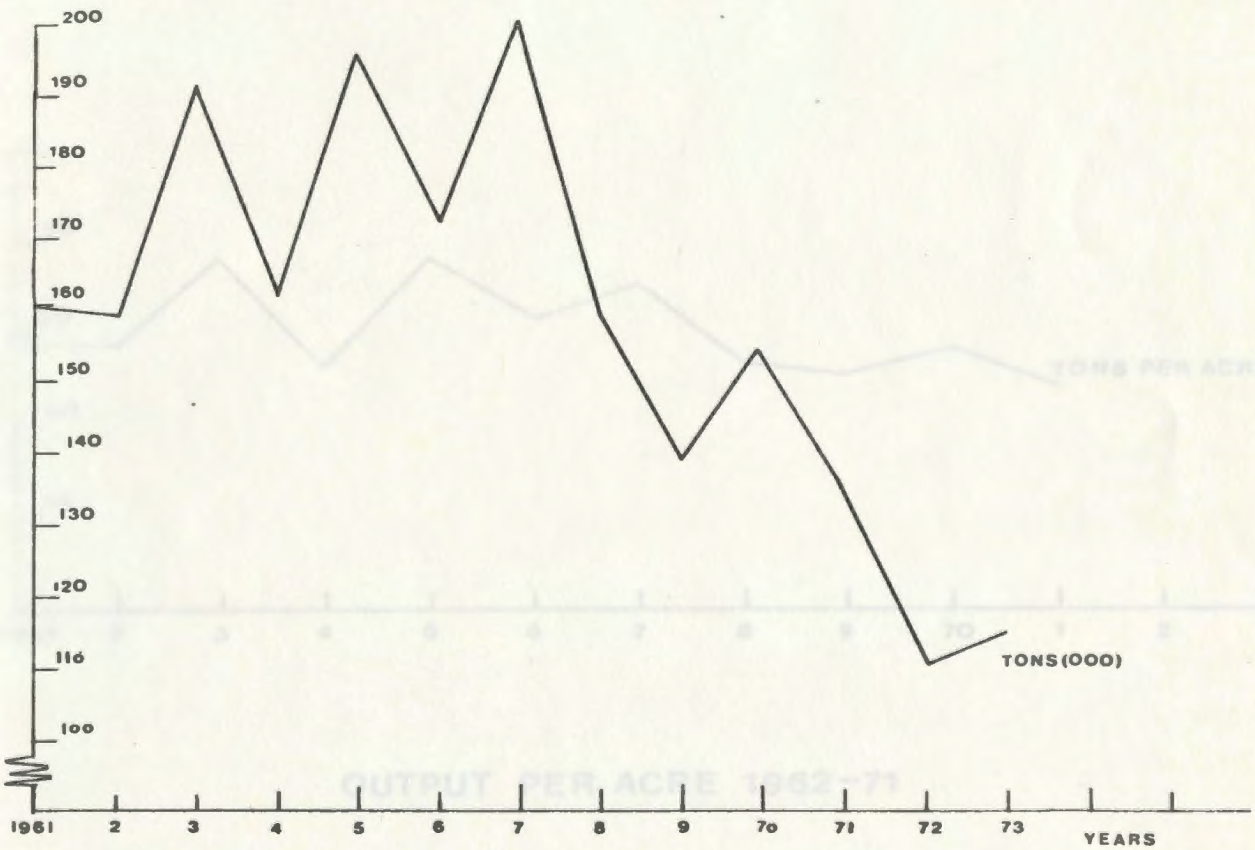
[1]Personal communication with Mr. Brathwaite, Senior Economist, Ministry of Agriculture, June 1973.

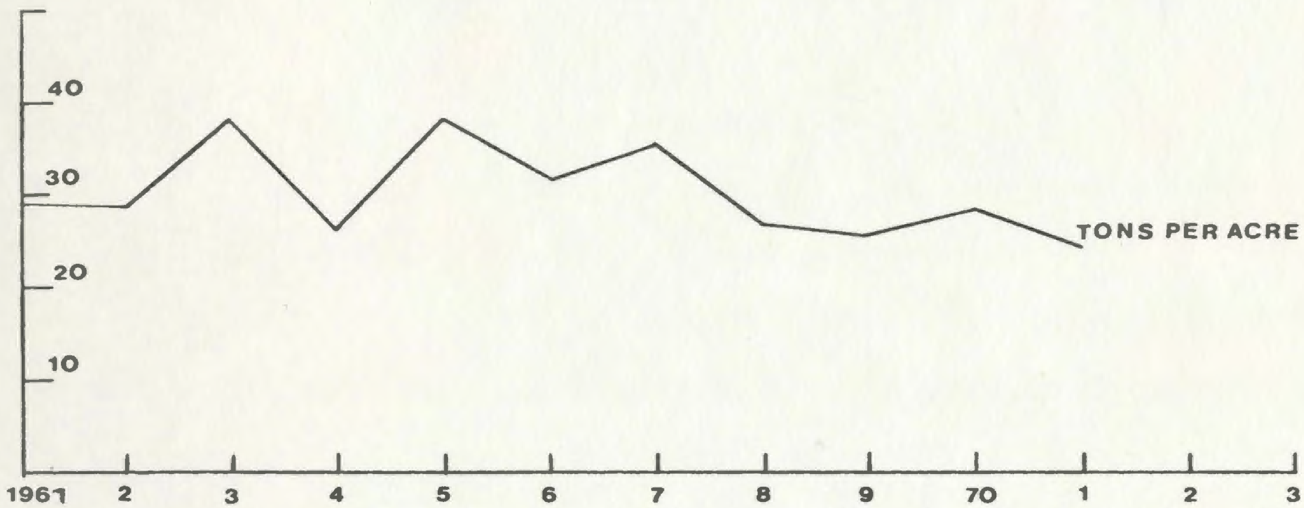
[2]<u>Barbados Economic Survey</u>, <u>op</u>. <u>cit</u>. 28:

Figure 2



SUGAR PRODUCTION 1961-73

Figure 3



OUTPUT PER ACRE 1962-71

climate, factory efficiency, variety of cane, soil conditions, pests and diseases.[1] These were also some of the factors used by agronomist, J.C. Hudson, in an article on production changes in the last few years. Dr. Hudson listed:

(a) Falling acreages, due to land use changes related to urban development, and changing agricultural usage. This factor is supported by a figure of 6,000 acres quoted by the Barbados Sugar Producers Association as the amount of land lost to cane in the last five years.[2]

(b) Falling cane quality due to extraneous matter or poorer sugar content;

(c) Varieties which are poorer than before;

(d) Compaction of the soil due to use of mechanical harvesters and loaders, along with a change from cane holes to furrows.[3]

There were other factors which he saw as contributing to the decline. Among these was the impact of cane fires. This led to the premature ploughing of fields and poorer yields from ratoon crops, as a result of the burning of the "trash" cover which helps to keep the soil moisture in and the creation of a simpler ecosystem in which parasites flourish. The situation has been aggravated by the abandonment of mulching for plant canes, a measure which has a similar effect to the burning off of the trash cover during fires. In addition there has been the effect of drought conditions during the last three years which have contributed to the lower yields.

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[1]Saint, Sir J., Sugar Production in Barbados During the Past 100 Years (1853-1953), Proceedings of the International Society of Sugar Cane Technologists Eighth Congress 1953, 966-974.

[2]Barbados Sugar Industry Review, op. cit., 2.

[3]Hudson, J., Fire Water and Sugar Production in Barbados (PAM), Barbados Sugar Producers Association, Warrens, 4, undated.

Finally two other problems have recently become crucial, the first of these being a shortage of labour. Historically sugar cane production for field and factory workers has been one of subsistence conditions compounded by a harsh working environment. Even today none of these have a stake in the estates on which they labour and wages are still very low. Because of this and the attractiveness of other forms of employment, people are leaving the industry. As a result it has become necessary to import harvest workers from the neighbouring islands of St. Lucia and St. Vincent (Table 2).

TABLE 2

Sugar Workers Imported for Harvest

Year	Number
1967	282
1968	752
1969	1110
1970	1227
1971	960
1972	975
1973	1020

Source: compiled from data supplied by Barbados Sugar Producers Association.

This is a very paradoxical situation when it is realized that the island has an unemployment rate of 13.4% of the population which is of working age.[1]

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[1] Physical Development Plan for Barbados, Town and Country Development Planning Office, Government Printing Office, June 1970, 11.

The second problem in many ways encompasses the others. It is the relationship between production and processing costs and market prices. This, it is claimed by the industry, is mainly a problem of "wages in relation to productivity" wages accounting for 52% of production costs and 27.5% of factory costs.[1] The answer seems more complex. With increases in the costs of labour and general overheads particularly machinery costs against a background of stable negotiated prices, the margin of profitability for the plantation is gradually eroded and this has been particularly severe on the more poorly located farms with reference to ecological conditions. The total impact of these problems has serious implications for the future of the industry but as has been noted, "This is not the first time that the Sugar Industry has faced a gloomy future, although perhaps the reasons for the apprehension are more complex than at previous times".[2]

In a recent paper published by the Agronomy unit of the Barbados Sugar Producers Association the problem was laid out in a few terse lines.

(a) There is enough evidence available before us to foresee the possibility of the rapid collapse of the industry if a massive effort is not made in the next few years.

(b) There are plenty of reasons for thinking that sugar production could fall near the 100,000 ton mark during the fight.

(c) There is also some justification that bold action on a broad front could enable us to continue to aim at 175,000 tons by compensating some inevitable yield losses with new approaches.[3]

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[1]Figures Supplied by the Barbados Sugar Producers Association, Warrens.

[2]Hudson, J., The Future of the Sugar Industry in Barbados PAM. Barbados Sugar Producers Association, Warrens, undated, 7.

[3]Hudson, J., Ecological Groupings of Barbados Sugar Estates PAM. Barbados Sugar Producers Association, Warrens, 16th September 1970, 8.

C. Solutions

It seems evident therefore that at this point in time there is a need for restructuring and reorganizing the Sugar Industry of Barbados to counteract the exigencies of the present situation. This involves changes at the production, processing, and distribution-collection levels. Additionally there are external factors such as price negotiations, particularly The Commonwealth Sugar Agreement which has to be reconsidered at the end of 1974, and the possibility of new markets. In an overall sense there are questions relating to ownership and control of the industry, and related problems, such as land use policies, which must be tackled.

It is with the transportation aspect of reorganization, along with some aspects of factory efficiency that this work is primarily concerned. While transportation costs are not the most crucial factor in the restructuring of the industry, yet it accounts for about 15% of total costs, incurring over $2,000,000.00 yearly. This is essentially in moving canes from field to factory (see Illustrations 1-6). Transportation costs were given very specific mention in the rationalization strategy of the Barbados Sugar Factories Limited. As stated, the intention, "Is to plan constructively for a higher standard of efficiency by reducing excess milling capacity, improving the factories which remain in operation, organizing cane deliveries to reduce transport costs and eliminate harmful competition for cane, and ensure better factory performance by avoiding time lost through inadequacy of cane supplies".[1] A solution to the scheduling aspect of the total problem might therefore lower total industry costs and help to reduce some of the present inefficiencies in the method of allocating canes to factories. In

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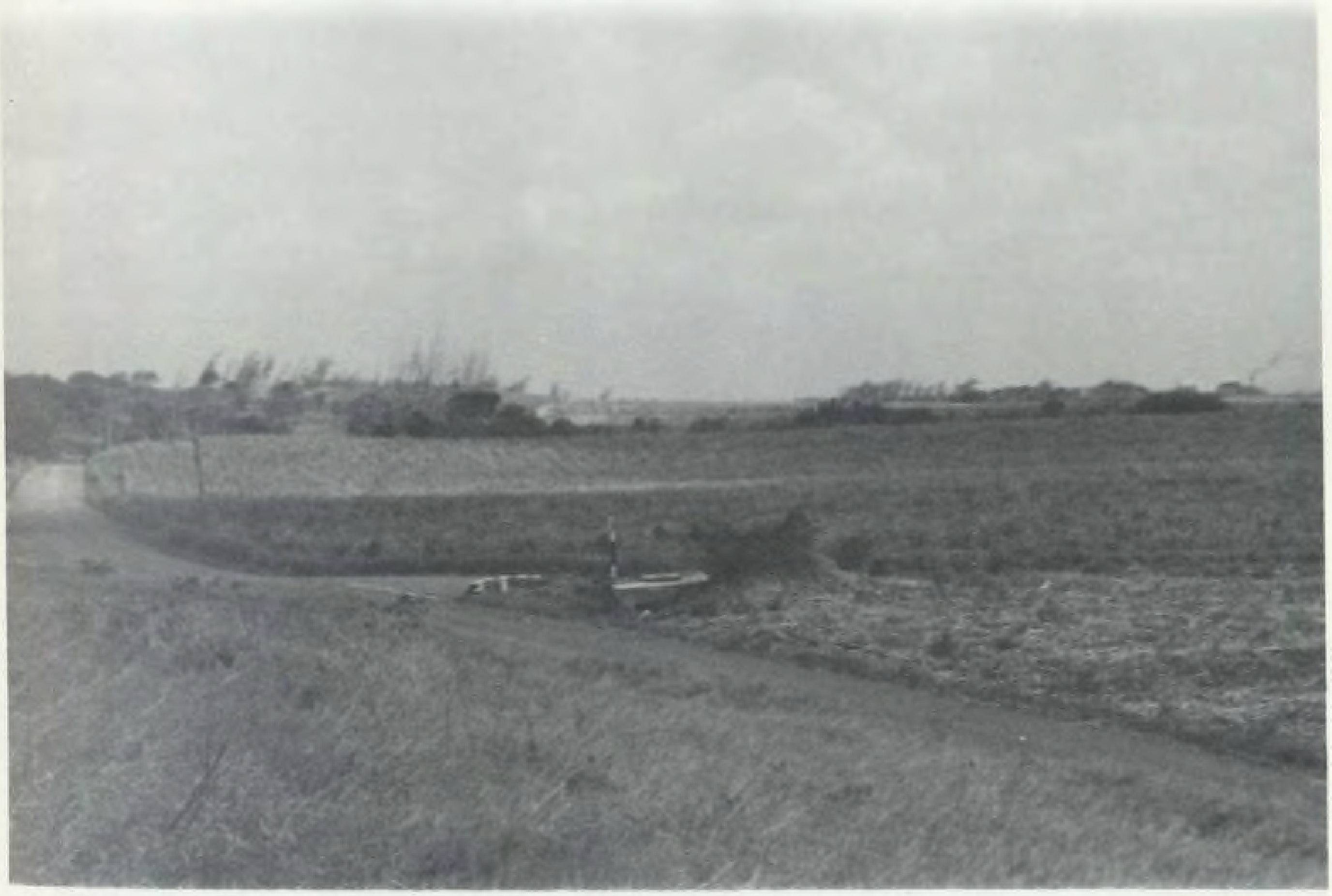
[1] Barbados, A Barclays International Economic Survey, Barclays Bank International Limited, 54 Lombard St., London, May 1972, 17.



Ripe Canes Before Harvest - In The Background
A Factory (Porters) in Operation

Mechanical Harvesting (McConnel Harvester)

Cleaning and Loading Hand Cut Cane. St. Philip.

Harvested Cane Awaiting Loading and Transportation.
St. Philip.

Cane Transport Using Tractors and Trailers.
St. Philip.

Unloading Cane at Factory Yard, Porters

a long term sense the thesis looks at the whole issue of centralization of the factory system particularly the location and allocation implications of change in this aspect of industry reorganization.

This research effort seeks therefore to provide the optimal solution for sugar cane movement in Barbados in terms of minimizing total haulage costs between canefields and factories. At another level it also seeks to provide the optimal locations for a more highly centralized factory system, and the consequent patterns of allocation which would result from this change.

Other aspects of transport efficiency have been dealt with before by Studniki Gisbert and W.D. Campbell.[1] Both of the above researchers dealt with cost-benefit analyses for cane transport systems on the island. Their particular contribution was to evaluate the impact of such variables as number of trips possible per day, number of transport units available, and the effects of depreciation, travel times and overheads including wages on total costs. Nothing was however done on a scheduling system from a spatial point of view. The present study therefore complements other work on the transportation component of industry costs. In the sugar industry allocations of cane between producing and processing centres are made yearly to facilitate the smooth running of factory operations, but these are done on trial and error basis. While it is not necessarily true that a different approach is much more efficient it is interesting to compare the results. This is therefore essentially a normative, model-oriented approach to the problem of location and allocation. In the final analysis the problem can clearly be defined as being geographical in nature in that it deals with the organization of economic activity over geographical space and the problem of development within a regional frame of reference. It therefore contains all those elements which Nystuen calls the Basic Geographic Concepts.

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[1] Barbados Sugar Industry Review, 15 March, 1973, 5.

(a). Orientation - a definite link and direction of flow between points, and a measure of intensity via a vector quantity;

(b) distance between areas, both in terms of physical separation (miles) or economic distance in terms of cost;

(c) connectiveness - relative positions in space.

All three of these Nystuen says are needed for the "Geographical Viewpoint".[1] This problem fits into the broader framework of general Economic Geography, specifically the type designated as Location-Allocation Analysis.

D. Structure of the Study

The following chapter presents the formulation of a research design and the methodology used for the analysis of the data, as well as a literature review of the theoretical implications and underpinnings of the study. Chapter Three gives the initial results for the 1973 harvest and an analysis of these findings, while Chapter Four looks at some aspects of sensitivity within the system specifically the impact of changing factory capacities on allocation results. Following in Chapter Five there is the centralization issue and the effects this has on both location and allocation processes. Finally in Chapter Six there is an evaluation of the work done, and an attempt to provide some assessment of both the methodological and empirical implications of the work.

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[1]Nystuen, J., "Identification of Some Fundamental Spatial Concepts", Spatial Analysis, D. Marble (ed.), Prentice Hall, Englewood Cliffs, New Jersey, 1968, 35-41.

II. METHODOLOGY AND DATA

A. Linear Programming

There are two distinct though related problems on which the research focuses. In the first instance it is one of scheduling flows of cane between current production and processing centres. For future planning the problem is one of rationalizing the factory system through the creation of a small number of large centrals, and an optimal scheduling of production to the new centres. The first is a problem of allocation while the second is a joint allocation-location arrangement. The methodology most appropriate in this context is therefore linear programming. It is a mathematical tool which has been designed for the allocation of scarce resources among numerous sources and destinations given a pattern of identifiable constraints. In any linear programming problem there are many alternative choices, hence the necessity of defining some limiting factors or constraints which precludes the use of all these alternatives simultaneously. These constraints are usually limits on capacities, demand or time in which a job can be carried out and must be capable of a precise mathematical formulation. An essential characteristic of a linear solution is that of equilibrium conditions. Total demand must equal total supply for the entire system and demand constraints of destinations and supply constraints of sources may not be violated.

The purpose of the algorithm is to optimize some objective function such as cost or distance minimisation, or the maximising of profits. Linear programming is by now a well established technique, its methodology and usage having been well documented elsewhere.[1]

Perhaps the most fundamental approach to linear programming is the Simplex Method. However where the structural properties of the problem are such that it can be represented by a Tableau of sources, destinations, distances and flows, the so called "Transportation Solution" provides a more efficient algorithm. In the context of this thesis the Transportation Solution is most appropriate. Symbolically the model is represented by

$$\text{(1)} \quad \text{Minimize } Z = \sum_{i=1}^{n} \sum_{j=1}^{m} t_{ij} x_{ij}$$

$$\text{Subject to } \sum^{m} x_{ij} \leq s_i$$

$$\text{(3)} \quad \sum_{i=1}^{n} x_{ij} = D_j$$

$$\text{(4)} \quad X_{ij} \geq 0$$

---

[1]For a historical treatment of the development of linear programming and its uses see,

Wagner, H.M., Principles of Operations Research: With Application to Managerial Decisions, Prentice Hall, Englewood Cliffs, New Jersey, 1969.

Garrison, W.L., "Spatial Structure of th Economy II", Annals of the Association of American Geographers 49, Washington, D.C., 1959, 471-482.

Scott, A.J., An Introduction to Spatial Allocation Analysis, Commission on College Geography Resource Paper of Annals of the Association of American Geographers, Washington, D.C., 1971.

Levin, R. and Lamone, R., Linear Programming and Management Decisions, Irwin Inc., Homewood, Illinois, 1969.

Literally this means (1) minimize total costs of commodity flows (x_{ij}) subject to (2) total shipments from a supply centre must be always equal to or less than supply capacities; (3) total shipments into destinations must be exactly equal to demand; (4) there can be no negative flows. When n is the number of destinations, m is the number of sources, ij are flows from any source i to destination j, t_{ij} is transportation cost. This is a static flow analysis intended to allocate flows of goods between different geographic locations in terms of some efficiency criteria. Each program has a main problem, the primal, and a dual or companion problem. The dual is represented by

(5) Maximize $Z = \sum^{m} D_j V_j - \sum^{n} S_i U_i$

(6) Subject to $V_j - U_i = t_{ij}$

(7) $V_j = t_{ij} + U_i$

(8) $V_i = U_j - T_{ij}$

Where D_j = j^{th} destination

V_j = price at j^{th} destination

S_i = j^{th} source

U_i = price at the j^{th} source

For the initial problem posed in this thesis the transportation model is capable of supplying two types of results. The primal solution gives an actual minimum cost figure for the entire island, as well as a scheduling system showing which plantations and peasant farm areas should send their outputs to which factories. The dual gives the competitive positions of the various producing units and at the same time creates a theoretical pricing structure. It is important to note that the results come from a normative model. The solutions do not explain present patterns, but rather show what should be an ideal situation given certain stated assumptions and data. As a result there are other significant results which can arise out of creating normative transportation solutions. The results can be viewed against actual patterns and the differences highlighted.

Discrepancies between normative and actual allocations may suggest a reorganization of flow patterns. Alternatively it may be more appropriate to consider the basic assumptions of the model which may not be in accord with reality. The difference can serve therefore to highlight some of the dynamic factors not taken into consideration by the model, but which are an essential part of a real life situation. For this model some of these assumptions are linearity, monopoly or perfect competition, and the idea that the important factors in an allocation decision are costs and capacities.

Following the initial use of the transportation model, a combined linear location-allocation algorithm is used. It seeks to find optimal locations. This is done by a series of alternating location-allocation steps until the final optimal locations and flows are found. Mathematically the problem is represented by

$$Z = R = \sum_{j=1}^{m} \sum_{j=1}^{n} a_{ij}\, wi \cdot \sqrt{(x_i - x_j)^2 + (y_j - y_j)^2}$$

Subject to $\sum_{j=1}^{m} a_{ij} = 1$ for all i

$$1 \sum_{j=1}^{m} a_{ij} \leq n-m+1 \text{ for all } i$$

Where R = aggregate distance

Wi is the weight of the j^{th} demand point

$X_1 Y_1$ are the cartesian coordinates of the I^{th} demand point

$X_{j1} Y_j$ = cartesian coordinates of the J^{th} centre

a_{ij} = 1 if demand point i is assigned to centre j

0, otherwise

This latter model is not an exact algorithm but a heuristic model which does not necessarily give an optimum global solution. These shortcomings are discussed later with the results.

B. Data Collection and Preparation

Three important groups of data are needed in the model. These are

(a) supply centres with known output levels;

(b) receiving centres with known demands; and

(c) connecting transportation links with known costs.

This material was collected from the Barbados Sugar Producers Association and the Ministry of Agriculture, Science and Technology. Initially there were 235 plantation and peasant farm units (figure 4) and their output was measured in tonnage of cane. Collection of production data for the small farmers poses a problem since their tonnage is very small per farm unit and official records only contained an aggregate figure. In order to arrive at an answer, the sixty four peasant zones identified on an official land use map 1970,[1] were measured with a Bruning Areagraph Chart (no. 4849) and acreages recorded. From this an average yield of cane per peasant acre was calculated based on aggregate production and total area, and the assumption that each peasant farm within the group was an "average" producer within his group. While the answers are not totally accurate this was the closest possible approximation in the circumstances.

For the 1973 harvest output was estimated as being 1,241,000 tons of cane for the entire island.[2] The output was processed by twelve factories

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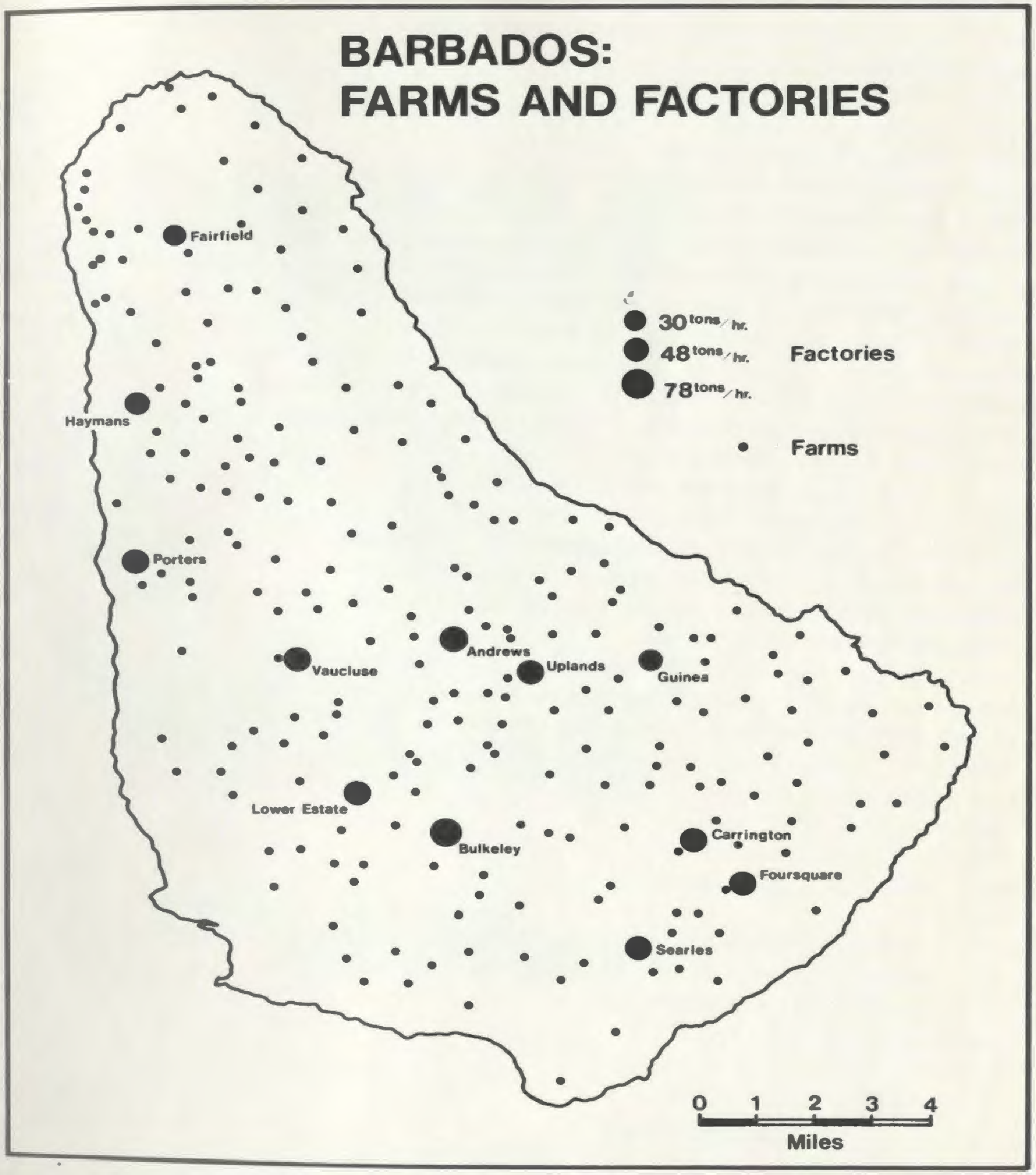
[1]Barbados Physical Development Plan, op. cit. Diagram 51.

[2]From files supplied by The Barbados Sugar Producers Association, Warrens.


BARBADOS:
FARMS AND FACTORIES
30 tons/hr.
48 tons/hr.
78 tons/hr.
Factories
Farms
Fairfield
Haymans
Porters
Vaucluse
Andrews
Uplands
Guinea
Lower Estate
Bulkeley
Carrington
Foursquare
Searles
0 1 2 3 4
Miles

whose capacities were given based on their hourly grinding rates and a six-day week of twenty working hours per day, assuming a sixteen week harvest (Figure 4).

The farm to factory distances were taken from Ordinance Survey maps of Barbados at a scale of 1:10000 produced by the Directorate of Colonial Surveys. These were then transformed into costs since there is a direct and constant relationship between these two variables (Figure 5). There are two types of cane transport systems used on the island - motor lorry and tractors with trailers. It has been calculated that there is a basic cost of $2.00 per ton for these two systems, based on an average distance of three miles between farm and factory. Each additional mile adds 2.4¢ to the lorry system and 3.3¢ for tractor arrangements. Specific costs could therefore be calculated by an appropriate adjustment in terms of both distance and mode.[1]

To facilitate the large size of the problems being analysed, the data was structured to fit computer package programs for the transportation solution and the location allocation problem. The version of the Transportation Problem used is the ICES program developed by the Massachusetts Institute of Technology. The code is written in FORTRAN E level subset language and was solved on an IBM/System 370 computer. The maximum number of data points capable of being handled in this package was 1050 arcs or source destination pairs. In this case there were 2882 possible arcs. Since the number of factories could not be reduced aggregation of the farms into larger blocks was necessary, and this was done using nearest neighbour aggregation. The other

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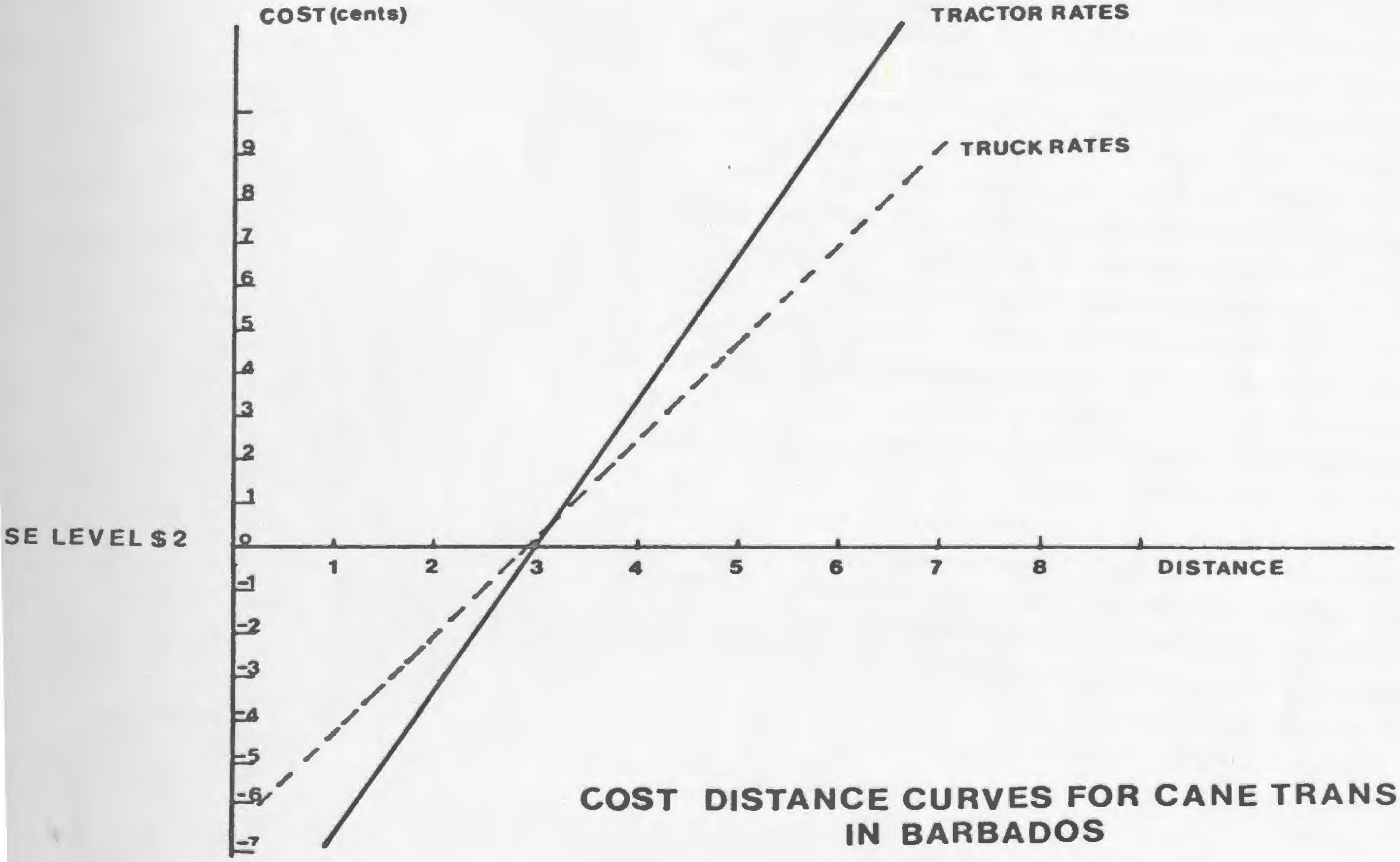
[1]Campbell, W., Cost Analysis of Cane Transport Systems, PAM Department of Agriculture, Economics and Farm Management, University of West Indies, Cave Hill, Barbados, 1972.

Figure 5



COST DISTANCE CURVES FOR CANE TRANSPORT IN BARBADOS

N.B. Costs were calculated using a base of $2.00 for a 3-mile haul. For hauls greater than three miles costs are adjusted upward and vice-versa for hauls less than three miles. Linear transport rates tend to prevail given the short haulage distances.

package program ALTERN was developed by L. Ostresh and soluble on the IBM/ 370 System also.[1] Being capable of handling 500 demand points and twenty centres it allows the full individual use of each data point. These programs were used to solve three problems in the research, two pure transportation problems for the years 1973 and 1974 and the joint location allocation decision as part of a long term reorganization strategy.

[1] Ostresh, L.M., Altern Heuristic Solution to the M Centre Location Allocation Problem, Computer Programs for Location-Allocation Problems, Monograph No. 6, Department of Geography, University of Iowa, Rushton, Ostresh, Goodchild eds. 1973, 55-66.

III. INITIAL RESULTS: HARVEST 1973

The initial results of the transportation model are for the sugar cane harvest of 1973. For this year there are twelve factories in operation processing canes for the 235 producing units which, for the purposes of the program, have been aggregated into eighty six units. As stated earlier there are two systems of information in each result:

(a) a study of cane flow patterns - primal solution; and

(b) a study of areal comparative advantage and a theoretical pricing structure for sugar cane - dual solution.

It is important to note that the solution is optimal only for 1973 since the result is totally dependent on farm output and factory capacities, and any changes in these variables would obviously alter the allocation patterns.

A. Primal Solution

The primal solution of the transportation problem yields the following results.

(a) the optimal volumes and flows of cane from all producers to all factories;

(b) the cost of each individual movement and a total cost for the entire island; and

(c) a complete commodity flow pattern for the sugar cane industry for 1973.

This information can be seen in Figure 6. The normative data was then compared with the actual pattern of cane movement which occured during the harvest (Figure 7). Actual costs incurred in the movement were $2,462,552,70 while normative model costs were $2,410,876.85. This implies a savings of $51,675.85 a year on an output of 1, 241,000 tons of cane. While this is

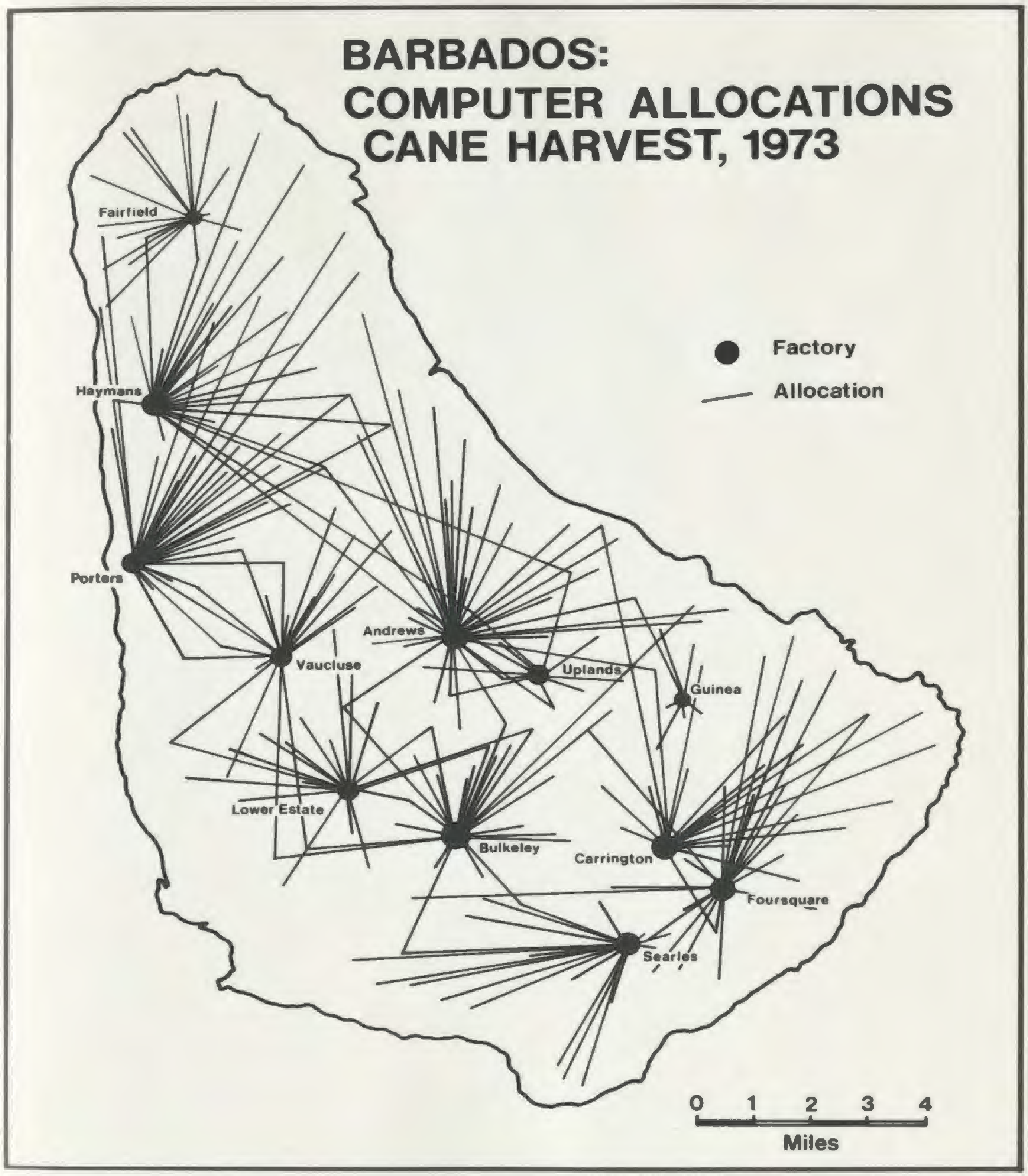
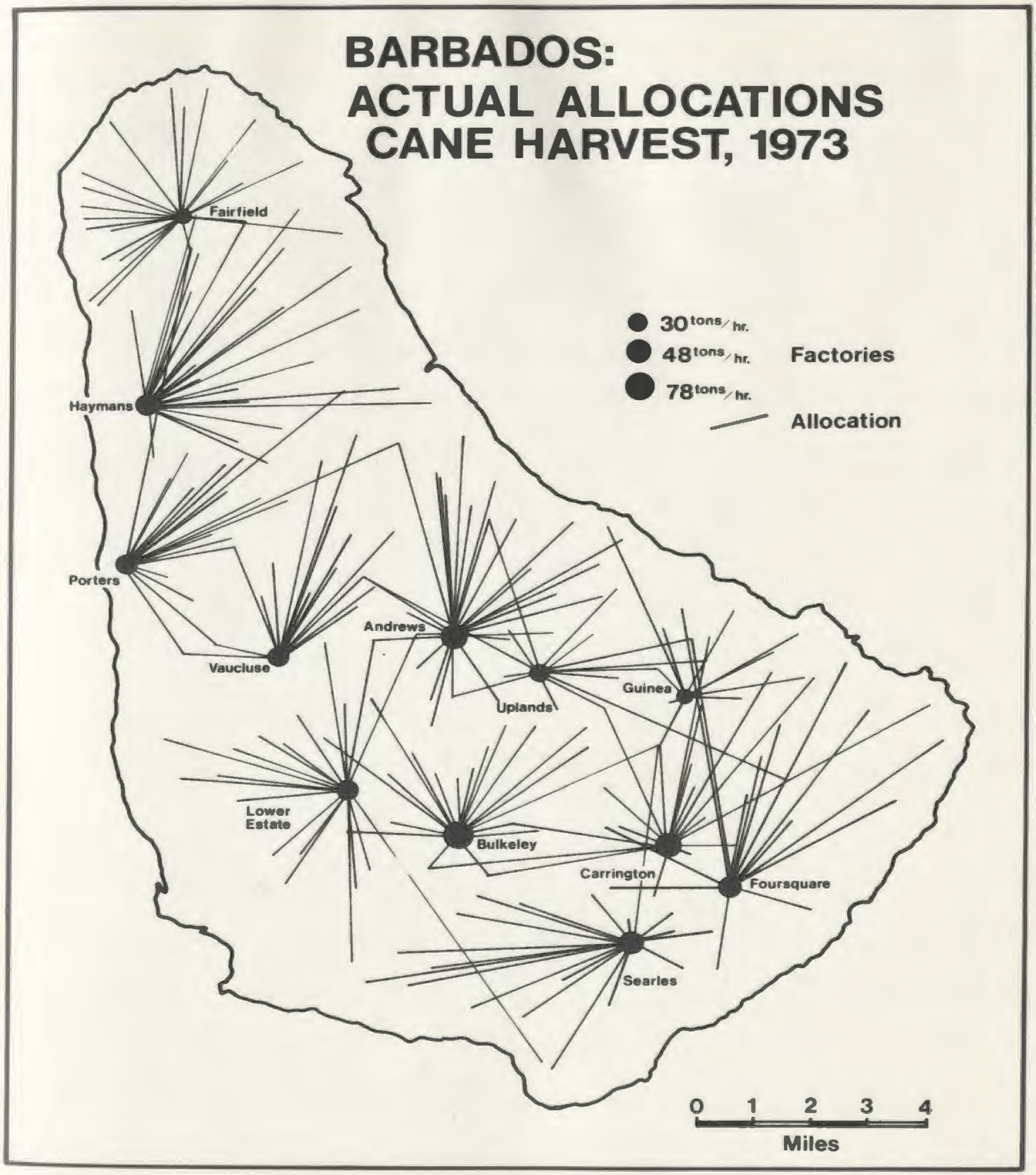

BARBADOS:
COMPUTER ALLOCATIONS
CANE HARVEST, 1973
Factory
Allocation
Fairfield
Haymans
Porters
Vaucluse
Andrews
Uplands
Guinea
Lower Estate
Bulkeley
Carrington
Foursquare
Searles
0 1 2 3 4
Miles

Figure 7


BARBADOS:
ACTUAL ALLOCATIONS
CANE HARVEST, 1973
30 tons/hr.
48 tons/hr.
78 tons/hr.
Factories
Allocation
Fairfield
Haymans
Porters
Vaucluse
Andrews
Uplands
Guinea
Lower Estate
Bulkeley
Carrington
Foursquare
Searles
0 1 2 3 4
Miles

only a 2.09% increase in efficiency, the difference in money is still significant for an industry which is as small as the island's is, especially when it is realized that individual farmers, some of them poor peasants, have to pay their own transportation costs. Besides, the output of cane for 1973 has been among the lowest ever and if production can ever reach the 1,826,000 ton level again, savings would increase to approximately $75,000 assuming the same level of efficiency. It should also be realized that this figure is not the absolute lowest total cost for a number of reasons. In the first place the need to aggregate the farms led to compromise over distances. This is so because the distances are no longer those of individual units but the larger resultant aggregations, and the effect seems to have been one of increasing the average costs between farm and factory. Secondly farms had to be aggregated not only on the basis of proximity to each other, but also in terms of mode of transport. This meant that it was not always possible to aggregate farms which were closest together since some were tractor transport users while others were lorry users. Together the net effect of the aggregation procedures led to longer distances and consequently higher costs between farm and factory. It would seem therefore that this approach to industry allocation decisions has something to offer in terms of efficiency and potential savings, and merits consideration.[1] It is remarkable how efficient the present method of allocation is coming within 2% of the normative model. This is achieved by an apparently non-mathematical approach to decision making, but a sound knowledge of local operating conditions. A close look at the two sets of data shows some variations in the patterns (Figures 6 & 7). The normative model contains a larger number of split allocations than the actual allocations made for this year.

Some of these are destined for three factories in a few instances. This is the case of Haggatts, Bawden, River and Turner Hall estates. There

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[1]For further discussion of limitations of the model see p. 82.

are also more double or two factory allocations in the model. Along with These are a few extremely long hauls in the normative solution not evident in the actual program for 1973. Canes from Malvern, Blackmans and Easy Hall are sent to Haymans factory bypassing Andrews and Porters factories which are nearer, as is Vaucluse factory. In the real allocation they went to Andrews alone. There is also the case of Forster Hall being routed to Carrington factory when in terms of distance Guinea, Uplands and Andrews were nearer. Actually canes from this plantation were processed at Guinea factory.

In the normative model, distance is obviously the major variable in that the normative and actual patterns are so similar. Assuming it really is, it seems that the 2.09% variation may therefore be explained by factors not explicitly considered in the model itself. Among these the following can be noted:

(a) There is a very strictly defined basis for the allocation system in the idealized model, costs, and capacities being the only factors which determine patterns of flow. The actual flows take into account a wider range of factors. For instance in the normative model there are a few flows which use shorter routes, but go over hilly terrain. These flows, usually from St. Andrew area to Haymans factory, (Haggatts, Turner Hall, Bawden and River estates) do not appear in the allocation made by the Sugar Factories Limited. Here is should be pointed out that this Scotland area of St. Andrew must use hilly terrain regardless of which factory it supplies, since it is located at the bottom of an escarpment and vehicles must cross the coral edge to reach any factory. However the roads to Porters, to which actual flows were made, are less steep and winding and more often used, and this could possibly explain a little of the differences.

(b) Traditionally each factory and estate was joined by common ownership through a small company or family unit. The first processing plants which were built were small wind or steam operated units to serve specific plantations. This led to alliances between specific farms and factories before the period when all factories became centralized under one management. Often then, actual routings were not related to least cost situations, but to factories with common interest and ownership. In addition, each privately owned factory competed for cane with all other factories through offers of better prices. Plantations were therefore able to shop around for the best deals even at the expense of larger haulage costs. Thus long standing alliances were built up for various reasons. The new factory organization still often respects some of these alliances even when they are not least cost and the specific aim of the centralized factory administration is to eliminate "harmfull competition for cane". For example Carrington Estates, Woodbourne and Chapelare somewhat closer to Foursquare factory than to Carrington factory. Thus while the actual allocation sends the output of these plantations to the traditional factory, the model allocates them to both Carrington and Foursquare. This alliance system can and should be changed easily since private competition among factories has recently been eliminated and so these flows, where they still exists, are products of inertia.

(c) Another emerging factor could be the recent introduction of mechanical harvesting equipment. In the effort to combat labour shortages, a large variety of harvesters have been brought into the island on trial bases. The methods of harvesting vary from cutting and loading whole canes (TOFTJ 150 harvesters) to the cutting and chopping of the cane into small lengths prior to transportation (DONMIZZI and MCCONNEL HARVESTERS). The latter methods need special unloading equipment at the factory yards, for retrieving chopped cane from the trailer bins for movement to the mill knives and grinding machines. This is a very recent innovation and many of the factories are only fitted out to move whole cane. It is also very likely therefore that allocations for the actual flows does and will have to take into account the method of harvesting used at the estates.

(d) The model seeks a global minimum solution taking the island as one whole. In this context the aggregate minimum figure is not merely the sum of many minimized parts. Thus in the overall minimum there are some individual flows which are not their minimum. A few thus get sacrificed to the overall good and this explains the few long hauls in the normative solution. In the final analysis we are dealing with a real system against an idealized pattern. The model simplified allocation in terms of quantifiable parameters and the other considerations such as management decisions based on terrain and other factors are not explicitly accounted for. The actual program could take into account a wider spectrum of decision making, and they could possibly also be programmed into the model.

One thing evident is that the industry is presently operating at a very high level of efficiency in its allocation arrangements. (See further discussion of "efficiency", p. 64-80.) It is still true, however, that this type of analysis could help efficiency particularly with the decreasing number of factories, where any inefficient allocations will be more costly than before.

B. Dual Solution

1. Theory of the Dual

It is stated earlier that both primal and dual solutions yield valuable results and these are both intimately related. In order to show the relationship and also the physical and economic interpretations of dual values this argument uses the same logic as that provided by Stevens[1] and

[1]Stevens, B., "Linear Programming and Location Rent", Journal of Regional Science, 3, 1961, 15-25.

Scott.[1] It is assumed that after the cane is harvested a group of private shippers buy the produce and sell it at the factory yards. The profit which each one makes on a farm to factory movement (ij) is

$$W_{ij} = (V_j + P) - (U_i + P) - T_{ij}$$

where W_{ij} = profit for one shipper

V_j = delivered price at factory

P = production costs

U_i = location rent

T_{ij} = transport cost

In a situation of perfect competition each shipper will attempt to gain as high a profit as possible. For the entire system this equates to total profits gained by each individual marketing agency combined.

$$W = \sum D_j V_j - \sum C_i U_i - \sum \sum X_{ij} T_{ij}$$

where D_j = total demand for canes by factories j   j = 1, 2, 3.....N.

C_i = output of farms i   i = 1, 2, 3.....M.

X_{ij} = amount of cane shipped from i to j

V_j = price at j^{th} destination

U_i = price at the i^{th} source

T_{ij} = transport cost

The $D_j V_j$ and $C_i U_i$ are equal to Z which is the objective function of the dual. Maximizing total profits is done by maximizing the differences between the primal and dual functions while maintaining both primal and dual constraints. This is done simultaneously by a theorem of linear programming. Eventually the maximum of the dual is the same quantity as the minimum of the primal problem. In an economic sense the traders will gain no profits, but by attempting to gain profits from the transactions, cause optimum

[1]Scott, A., An Introduction to Spatial Allocation Analysis. Commission on College Geography, Resource Paper 9, Annals of the Association of American Geographers, Washington, D.C., 1971.

solutions for both primal and dual programs. There is therefore a constant mathematical relationship between these two aspects of linear programming. The rationale for studying the economic meaning of duals has been stated this way by Solow et. al.

> The dual and its connection with valuation invite us to apply linear programming to the study of markets and prices as well as to the direct study of production and allocation.[1]

Stevens points out that there are two key variables in the dual, shadow prices at source (U_i) and at destination (V_j) and the dual function is defined as maximizing differences between source prices and those at destination. To understand the workings of the dual it is assumed that there is a demand for DD tons of cane to be used at a factory located at j and there are four estates which could possibly satisfy the demand. These farms are labelled W, X, Y, Z (Figure 8). If a constant production cost is assumed the individual delivered price from the nearest farm will be OW with Te being tonnage supplied from W. Factory j begins by buying as much as possible from the nearest farm since its delivered price is lower due to a small transportation cost. V_j is the equilibrium delivered price at the factory and OW the price on canes from the first farm. Theoretically the factory first exhausts the nearest supply and gradually moves outward until its full demand is finally met. Notice there is therefore a supply curve SS which has a step function. This is because when farther supplies have to be tapped the delivered price must rise enough to cover the extra costs involved. In a true competitive setting it is quite likely that each seller would increase his price to just below the level at which a farther farm could replace him in that market. This, if unregulated, could lead to a chaos in market pricing. However since the factory has to use supplies from distant farms, and nearer

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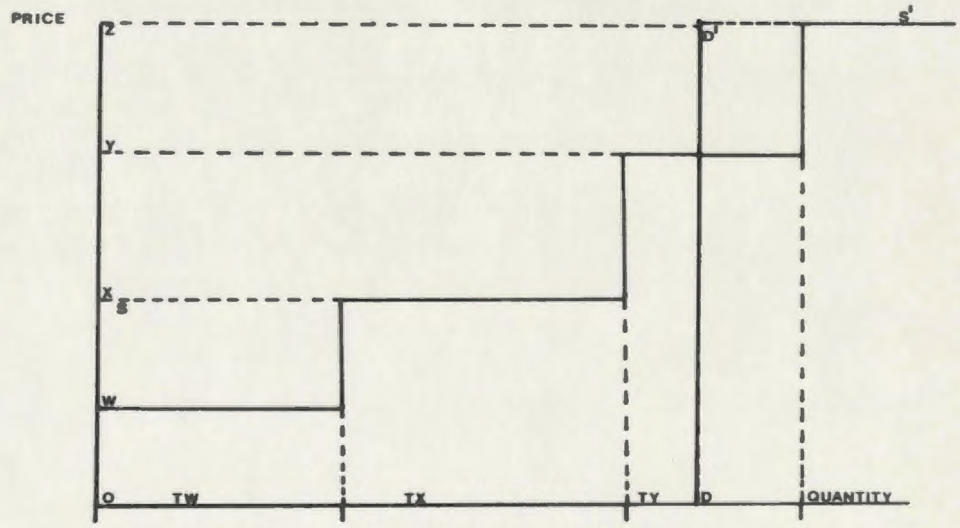
[1]Dorfman, R.; Samuelson, P.A. and Solow, R.M., Linear Programming and Economic Analysis, McGraw Hill, New York, 1958, 59.

Figure 8



DEMAND AND SUPPLY CURVES FOR THE TRANSPORTATION PROBLEM (AFTER STEVENS) farms could always undersell the more distant ones in any price war, stability can be possible. Equilibrium is reached when farm W delivers TW tons, farm X, TX tons, Farm Y, TY tons and the final farm, TZ tons of cane all delivered at price OZ. Now we have the meaning of V_j. It is the equilibrium price delivered at the factory yard regardless of where the supplying farms are located. These prices are only meaningful if there is a monopoly situation existing. The Barbados Sugar Industry, particularly the factory system, is very clearly a case of monopoly control, since the recent consolidation of all previous existing factories into one company under a single management. For this reason the idea of equilibrium prices can be looked at and some meaning attached to them.

2. Equilibrium Prices

For the 1973 harvest the following system of equilibrium prices was computed

TABLE 3

Andrews	196	Haymans	191
Bulkeley	195	Lower Estate	197
Carrington	195	Porters	198
Fairfield	185	Searles	195
Foursquare	195	Uplands	191
Guinea	189	Vaucluse	195 (Cents/ton)

The delivered price at each factory is a function of the spatial competition for cane sales among the various estates and peasant farms. It is also indicative in a theoretical sense of the competition between factories for limited supplies of cane. This last seems more crucial. These varying prices say something of the capacities and hinterland size of the factories.

In a general sense the factories with lowest delivered prices are those with the smallest capacities particularly Guinea and Fairfield. It is of significance to note that these two factories are also the same two which will cease grinding operations as from 1974 due to age, inefficiency and small uneconomic size. At the other extreme the factories with the largest factory yard prices are not necessarily the largest factories in terms of grinding capacities. Porters is the fifth largest factory in the entire system but has the highest delivered price while the factory next to it in terms of price, Lower Estate, is sixth in size. Here these prices related also to the value of the surrounding land. In the case of Porters and Lower Estate they were forced to draw cane from very distant suppliers so increasing transport cost and therefore prices. This of course reverts to the fact that the crucial factors involved in this system are capacities of factories per unit time, the size and locations of farm units surrounding the factories and the areas which each factory draws on for supplies to feed their mills.

These factory prices can be used to help determine the price to be paid for cane for each producer. The resultant structure of prices would give a return to each producer reflecting the exact situation value of his site. This is because with the equilibrium base price and differential transportation costs the overall cost variance between farms would be only the differences in relative locations. The equilibrium price would therefore help to give each producer his specific advantage and balance against the fact that no account is presently being taken of differences in the juice quality of different estates. In the case of stale, burnt cane where juice quality has deteriorated to the extent that penalty deductions are made, these deduction rates could easily be fitted into the total pricing structure. The chance to improve on price calculation by the addition of another factor which could make the structure more realistic also seems to be potentially fruitful for further meaningful changes in the industry.

3. Location Rents

Location rents can be evaluated for the plantations because there is a known transport rate which changes as a regular function of distance (Figure 5). The value difference between an origin and a destination cannot be more than the transport costs involved in moving cane from farm to factory. In economic terms then the U_i values are location rents according to the classical definition. This theory is best known in the Ricardian formulation where land is the scarce factor. Ricardo postulated that as agricultural output increased due to a demand factor the number of farms will also increase. Eventually the farms developed later must be sited on increasingly less fertile land and will therefore incur higher production costs. The difference between price and cost is location rent including normal profits. W. Felner stated:

> Competitive price is determined by the cost at the margin of production where cost included no rent but merely wages and profit.[1]

Rents in this case are generated not by fertility, but by distance and costs. There are two conditions which must be fulfilled for this stability. Flows outwards from farms must equal intake at the factories and price at the factory must exceed farm price by the amount of the transport cost per ton. Thus, price is determined by the delivered price of the farm farthest away that actually supplies the factory under consideration. This estate earns zero rent while the ones in closer proximity receives different rents exactly equal to the amounts which they save on transportation. This is similar to

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[1]Fellner, W., Modern Economic Analysis, McGraw-Hill, New York, 1960, 98.

von Thunen's analysis in which he pointed out the tendency for economic rent to decline for a given land use as distance to the market increased. Assuming the condition of ceteris paribus and variable transport costs price declines linearly (assuming a linear decay function) and so does economic rent assuming that land use intensity is constant according to the formula.

$$E = (P-C-Td)y$$ [1]

where E = economic rent per acre

P = price per ton

C = costs excluding transport per ton

T = transport cost per mile per ton of cane

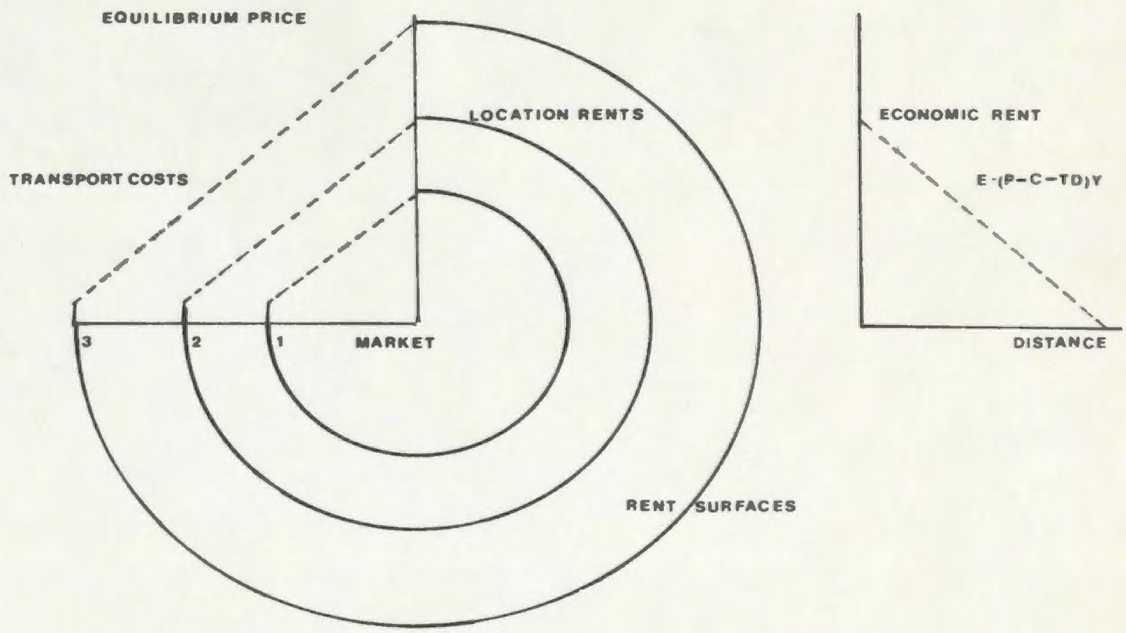
D = distance miles to market

Y = yield per acre (see Figure 9)

Notice that these location rents are calculated only on marginal tonnage for each plantation. Therefore a small output on a high rent location such as is the case with Pleasant Vale and Indian Pond earns as much per ton as larger estates can, on equally favoured land. If, for example, nearer farms increased production to the extent where they could satisfy factory demand, then the outer regions would theoretically go out of production or more practically supply another one. The dual therefore gives location rents per ton on marginal amounts of both land and factory capacity. The V_j can now also be viewed as location rents for the factories. By now it is apparent that transport costs are essential for the determination of location rents. This view of the U_i values is one of Stevens contributions to the interpretation of linear programs and is distinct from the theory of Spatial Price

[1] Found, W.C., A Theoretical Approach to Rural Land Use Patterns, McMillan, Toronto, 1971, 59.

Figure 9



THE GEOGRAPHICAL INTERPRETATION OF THE DUAL

Equilibrium as defined by Samuelson.[1] As Stevens put it

> Once the dual is thought of as a location rent system the V_j becomes merely another such set of rents not really different in kind from the U_i's themselves.[2]

He pointed out that the rents in question are earned by the more distant factories at rates discounted by the transportation costs. The whole concept of location rents has been summarized by Marshall:

> If two producers have equal facilities in all respects except that one has more convenient situation than the other, and can buy and sell in the same markets with less cost of carriage his differential advantage....is the aggregate of the excess charges for carriage to which his rival is put....this becomes the situation value of his site.[3]

In our system, location rents determine the relative values of sugar cane producing lands in relation to the factory system. More specifically it gives a "relative advantage surface" which immediately shows those farms better located relative to the factories (Figure 10). For the island as a whole the value of site varies from zero to eighteen cents, Eastern Caribbean currency. The map shows three zones of best location. The largest area includes Edgecumbe, Sunbury, Bulkeley, Jordans, Brighton, Buttals and Windsor estates. The next group contains the plantations Claybury, Auburn, and Tamarind Hall. There are also two individual estates Vaucluse and Redlands with highest rents. All these areas earn the highest rent of eighteen cents. From these areas the surface grades outwards into successively lower rent areas and finally fades away into the worst located areas of Golden Grove and Bannatyne and the zero rent estate Morgan Lewis. There is no regular pattern from high to low rent areas as indicated by the fairly complex nature of the

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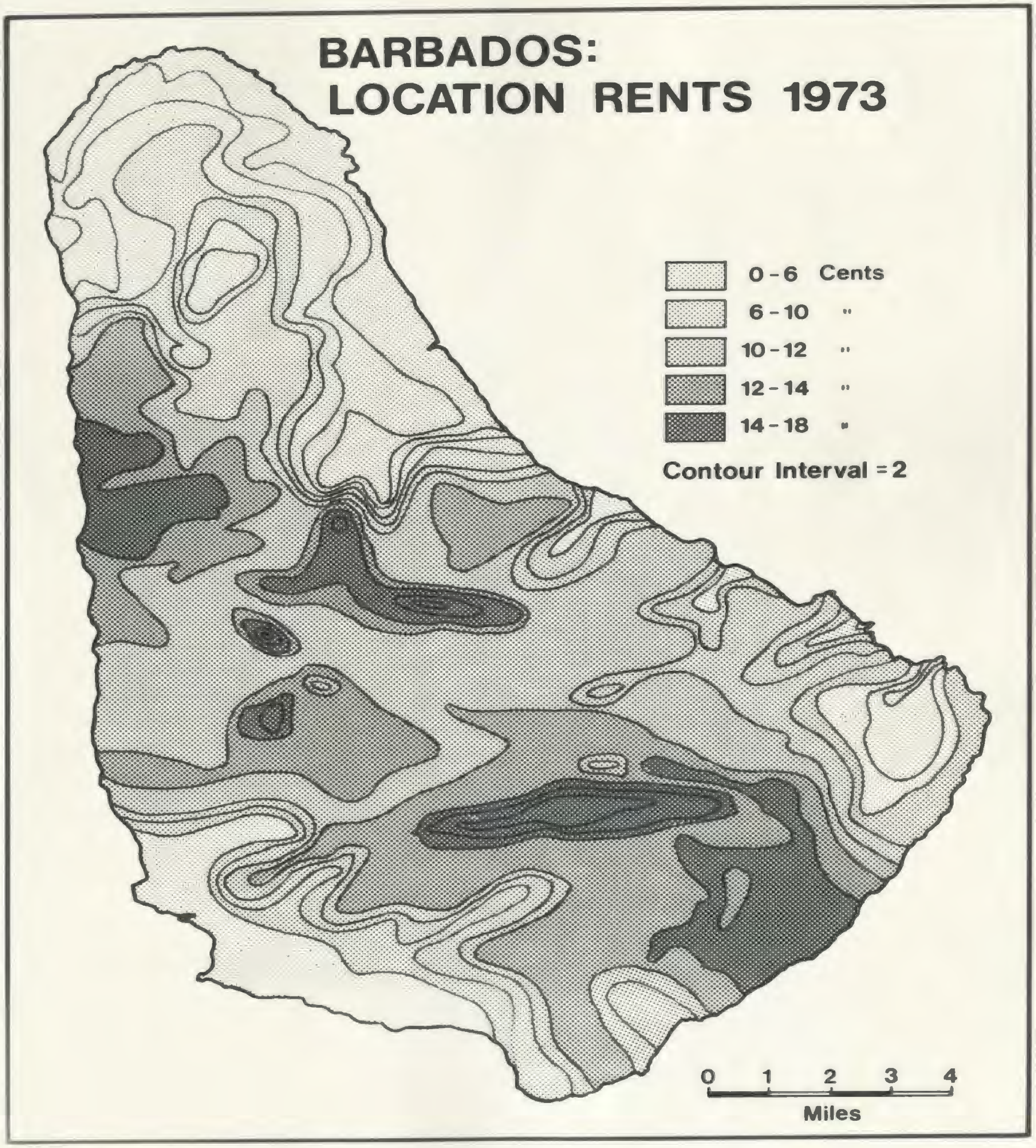
[1]Samuelson, P., "Spatial price equilibrium and linear programming". American Economic Review, 42, No. 3, 1952, 283-303.

[2]Stevens, B., "Linear Programming and Location Rent", Journal of Regional Science 3, 1961, 15-25.

[3]Marshall, A., Principles of Economics, London McMillan (7th edition) 1916, 441.

Figure 10


BARBADOS:
LOCATION RENTS 1973
0 - 6 Cents
6 - 10 "
10 - 12 "
12 - 14 "
14 - 18 "
Contour Interval = 2
0 1 2 3 4
Miles

surface with its many troughs and peaks. This is due to the very noticeable size differences between the estates, and the large number of factories often fairly close together. As a result there is an intricate pattern of allocation which leads directly to a complicated rent surface. In addition the factories with their long hauls noted earlier, create anomalies where a farm can have very low rent and yet be in close proximity to areas of high rent. This is true of the difference between Vaucluse, eighteen cents, and Exchange with a rent of eight cents. In order to make the pattern more comprehensible the island was divided into five groups on the basis of rents, ranging from highest to lowest. The best areas are found in the St. George Valley and running into St. John's and part of St. Philip around Edgecumbe plantation. There are also areas of highest rents at the border of St. Michael, and St. George, and in St. Thomas going into its contiguous region in St. Joseph. The largest area fits into the second highest rent zones. Generally this is the rest of St. George, and St. Thomas and the large portion of central St. Philip and Christ Church. Another area in this category is the western terraces of St. Peter and James going up to the edge of the coral escarpment around Apes Hill and Gregg farm. In contrast the worst areas occurred mainly in four parishes. The two most significant being the St. Lucy table land in the north of the island and its adjoining area St. Andrew particularly the Scotland district. Other areas of poorer location in relation to the factory system were most of St. Michael particularly the built up area moving outwards from Bridgetown and going into the coastal areas of Christ Churh, which is also a heavily residential area. Another small area is in the South Eastern portion of St. Philip stretching to the coast.

4. Marginality

The concept of location rents implies differences in locational advantage and a grading into areas on the basis of some form of situational advantage. From this idea comes another concept, that of marginality. This idea stems from the whole theory of rent discussed earlier and has its definition in the literal meaning of margin, an edge or border. In its original economic context it referred to those plots of land which were so poorly endowed in terms of good soil and fertility that they were on the borderland where productive land disappeared into unproductive areas agriculturally. There is also the obvious implication that in any retraction of the area of farmland under production, these marginal areas would be the first to be abandoned. From this base the concept of marginality has broadened to become applicable to any situation and can be defined as being any area or product which has the lowest value or utility given a specific criterion or set of criteria. In the context of location rents therefore marginality is a relative thing, dealing with relative accessibility to the island's factory system. The marginal areas are those which earn lowest rents by virtue of being so far away from the specific factories they supply with cane. In a strict sense the marginal areas are those which earn zero rents and in this case there would be only one plantation in this category, Morgan Lewis in the Scotland district. However given a range of eighteen cents between best and worst areas, marginality was arbitrarily defined for the purpose of this study as being those areas earning a rent of six cents or less. This was done because of a large number of farms earning below six cents, often only about three cents in fact, and also because we are dealing with a relative rather than absolute concept. What the classification really says is that the areas earning six cents or less are the worst located and as one goes progressively higher (rents wise) the areas become more accessible.

This aspect of the value of site is one of the two important aspects of total site value in the sugar industry. The other facet, perhaps much more important, refers back to the original Ricardian idea of the value of land as a producer of agricultural products in this case, cane. It was therefore decided to look at value in terms of productivity of the various areas and see if there is any relationship between these two concepts of rent.

In a recent survey carried out by the agronomy unit of the Barbados Sugar Producers Association, the island was divided into ecological groups. The classification embraced all the significant factors affecting production. These included rainfall, soils, and potential evaporation rates. To these were added slopes and ease or otherwise of mechanising farming operations. Finally an extra hazard, fire, was included and it is significant to notice there was a specific category which was called "economically marginal". This referred to areas where first ratoon yields averaged less than twenty six tons of cane per acre, or fell below twenty tons per acre before the fifth crop. Using these criteria a system of twenty one ecological groups were reached ranging from A to U and each characterized by an average yield of cane per acre. For example Group A is characterised by

(a) less than fifty inches of rainfall annually

(b) soils mainly 30^s and P^s

(c) areas of high evaporation

(d) twenty nine point six tons cane per acre of upper quartile yields

(e) economically marginal with fire since 1968

In terms of slopes the following categories are typical of group A.

three percent of land in slope group A

twenty two percent of land in slope group A/B

nineteen percent of land in slope group B

thirty two percent of land in slope group B/C

twenty percent of land in slope group B.

Also included in the grouping was the fact that forty four percent of the land in this category is easily mechanisable, fifty two percent mechanisable with care, and five percent diffiuclt or impossible to mechanise.[1]

For ecological marginality the groups were put into five categories from best to worst and mapped (Figure 11), ranging from 47.1 (group U) to 25.4 tons per acre of cane (C). From the two sets of data dealing with value, a composite map was drawn up (Figure 12) using a combined scaling of ecological group and location rents. Now the concept of marginality has a more genuine application. Five categories were created.

(a) Best areas earning rents of thirteen and above and having a yield over forty tons;

(b) areas earning rents over thirteen and yields between thirty three and forty or rents seven to thirteen with yields over forty;

(c) areas earning rents of seven to thirteen and yields thirty three to forty tons, or rents below seven but yields over forty tons;

(d) zones with rents over thirteen but yields between twenty five and thirty three tons per acre, or rents below seven and yields thirty three to forty tons; and

(e) the worst areas - these earn rents of below seven and yields twenty five to thirty three tons or rents of seven to thirteen cents with yields twenty five to thirty three tons per acre of cane.

These areas then tell us where the best and worst sugar canelands in Barbados are, based on all the factors which affect production and transportation to the factories. Notice also that in the scaling yields are given a

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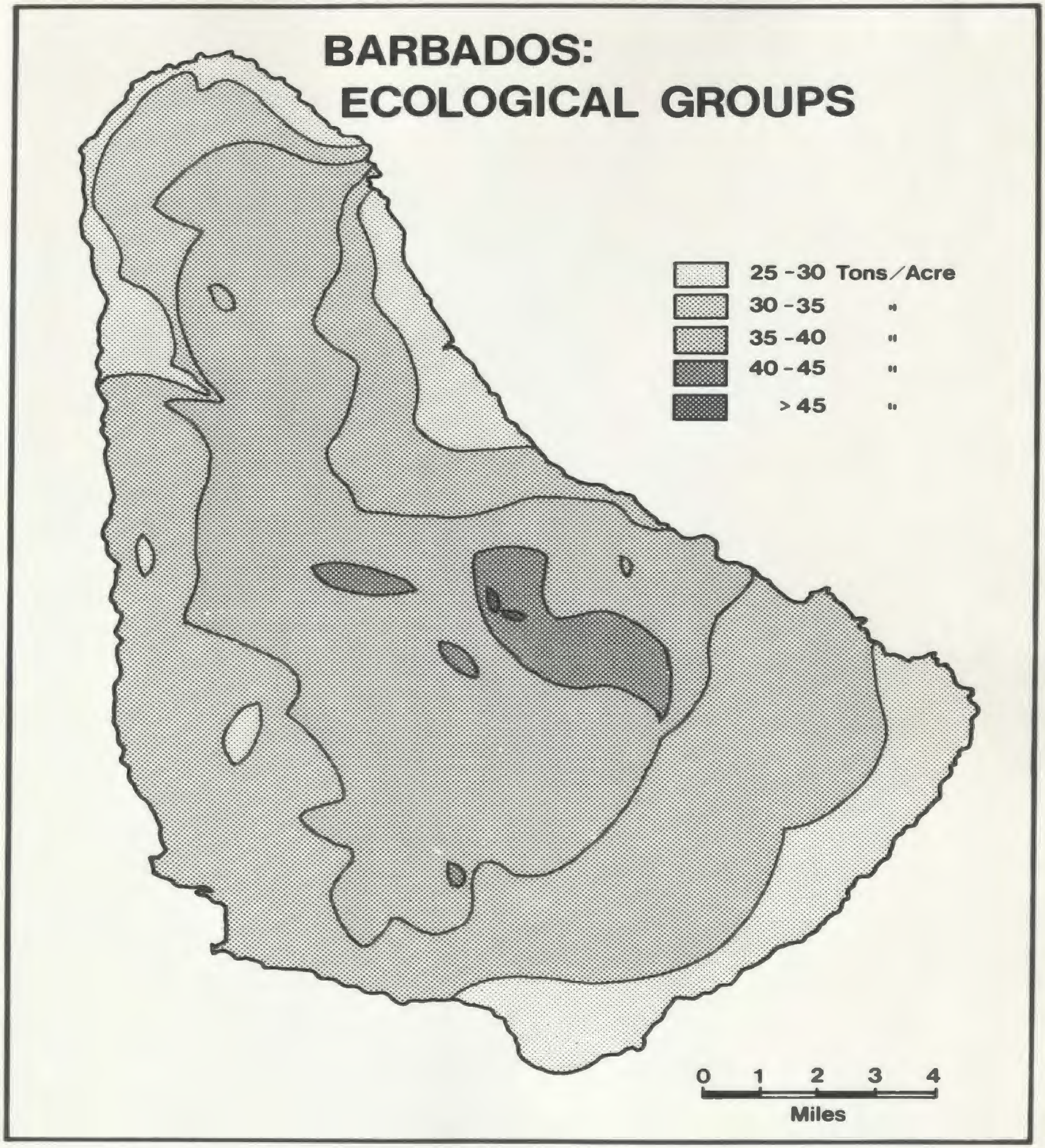
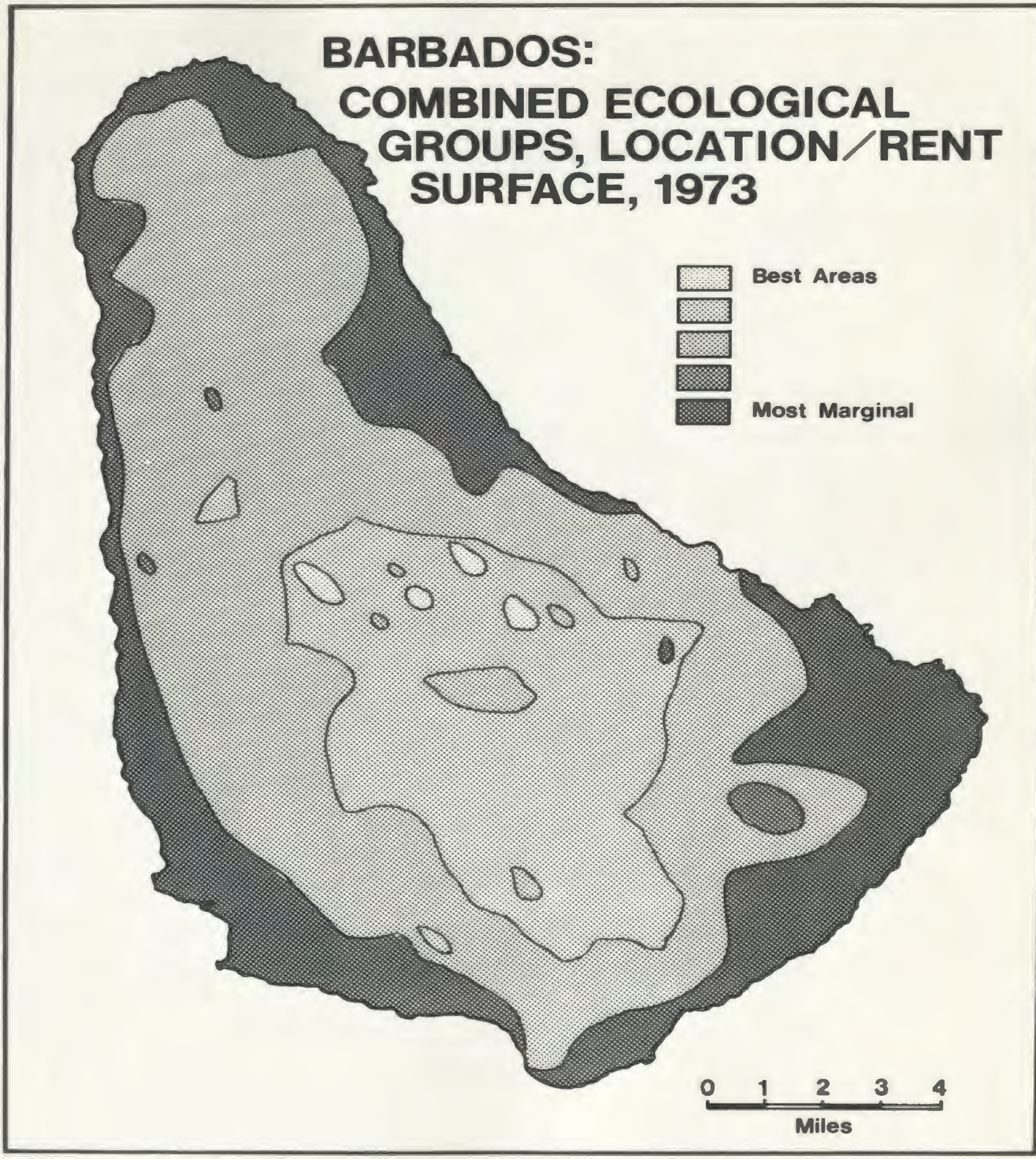
[1]Hudson, J., op. cit., table 2.


BARBADOS:
ECOLOGICAL GROUPS
25 - 30 Tons/Acre
30 - 35 "
35 - 40 "
40 - 45 "
> 45 "
0 1 2 3 4
Miles


BARBADOS:
COMBINED ECOLOGICAL GROUPS, LOCATION/RENT SURFACE, 1973
Best Areas
Most Marginal
0 1 2 3 4
Miles

heavier weighting than rents. This is done since rents are relative and can change given changes in the factory system, while ecological ratings are (in the short run) fixed and absolute. It is also true that agronomic conditions are more important then relative location in determining the viability of any plantation within the Barbadian Context.

A close look at the composite map shows significant relationships, though it should be noted there is no absolute relationship between yield ratios and location rent categories. One reason for this is the fact that optimality is largely influenced by agronomic conditions. However, usually the areas of highest rents are also areas of highest yields. These are the estates Woodland, Redlands, Castle Grant, Claybury, Tamerind Hall, Auburn, Pleasant Vale and Lion Castle. There are also the second best areas which show close relationships including the high rent zones of St. George, Thomas and St. Philip which showed up on the location rents map. At the other extreme there are the marginal areas with both low yields and medium to low rents. Here again the St. Lucy estates, Harrison, Colleton, and so on were highlighted. The other significant group is in the St. Andrew area generally and the Scotland district specifically, with Haggatts, Turner Hall, Bawden and River among others, being worst located on the total value surface. From this region comes Morgan Lewis which is the estate of lowest yields for the island, 25.4 tons per acre and is also worst located having a rent value of zero. The other worst off areas are those around the built up areas of St. Michael and Christ Church. These are just slightly better off than the St. Lucy and Scotland region estates. Of the anomalies (high rent low yield) there are only five estates in this group - Sunbury, Trents, Congo Road, Harrow and Grove. The other type of anomaly (high yield low rent) has only one representative, Clifton Hall plantation.

There seems to be one basic reason why there is such a close relationship between the two factors location rents and productivity. Initially the best areas for cultivation were opened first, and the more marginal ones later, because of booming sugar prices and ready markets. The factory system, which came after the plantation system was developed, was built initially around the core areas of production which gave these areas a total advantage. Later with the gradual closing of many factories, particularly the smaller ones, the pattern was for those on the more marginal areas to go. The removal of Spring Hall (St. Lucy), Haggatts (St. Andrew), Warrens (St. James), Belle (St. Michael), Three Houses (Southeastern St. Philip), Kendal (St. George) in the last decade or so testifies to this fact. The recent removal of Fairfield (St. Lucy) and Guinea (St. John) for 1974 again seems to support this. It seems also true that the larger and better equipped factories are always usually in the core areas of cane production.

The results of this analysis can have a serious implication for future land use planning for the Island. As stated earlier the concept of marginality implies that in any retraction of the margin of profitable cultivation, or changes for any reason, the worst areas would or should be released first. The composite map shows where these are. The importance of this is strengthened by the fact that the sugar industry has been facing many pressures. These include increasing encroachment by residential and other non agricultural usages. Also important is the recent use of mechanical harvesters and types of equipment needing flatland. Finally there have been drought conditions experienced over the last three years which have caused many areas on the lower rainfall groups to cease production. There is, at this stage, a need for fundamental restructuring of the whole industry, which will also include a retraction of the margin of production so that new types of farm operations can be conducted. The composite map shows the areas which should logically go first in any changes which may occur. The two major regions should obviously be the St. Lucy and Scotland districts followed by the other marginal regions now under cultivation, if it becomes necessary.

IV. OPTIMIZATION UNDER PARTIAL CHANGE

The initial solution posed questions on the sensitivity of the results and their stability under changing conditions. What changes in both the primal and dual solutions could be expected if there were changes in the parameters which control the model? The 1974 harvest helps to answer this question in relation to changing factory capacities. Two factories, Guinea and Fairfield, have been scrapped from the end of the 1973 harvest, and this raises the question of how the surplus cane will be allocated, and how the overall situation will be affected by their withdrawal. This has led to changes in the capacity constraints of the remaining ten factories. Usually this is calculated based on a typical harvest period of twenty hours for a six day week and a total duration of sixteen weeks. If bumper crops occur, or any other factors which affect current production and/or capacity levels, the season is extended for as much as twenty weeks if necessary to accommodate the increase. For this harvest, therefore, capacities for the factories were based on an eighteen week harvest and normal operating rates. The assumption seems reasonable since there were no plans to increase the working rates of any remaining factories for this year with new machinery.

TABLE 4

Factory Capacities for 1973 & 1974

Factory	1973	1974	Grinding Rates (Tons of cane/hour)
Andrews	144,000	157,680	73
Bulkeley	155,200	168,480	78
Carrington	102,000	129,600	60
Fairfield	68,000	-	30

TABLE 4 (cont'd)

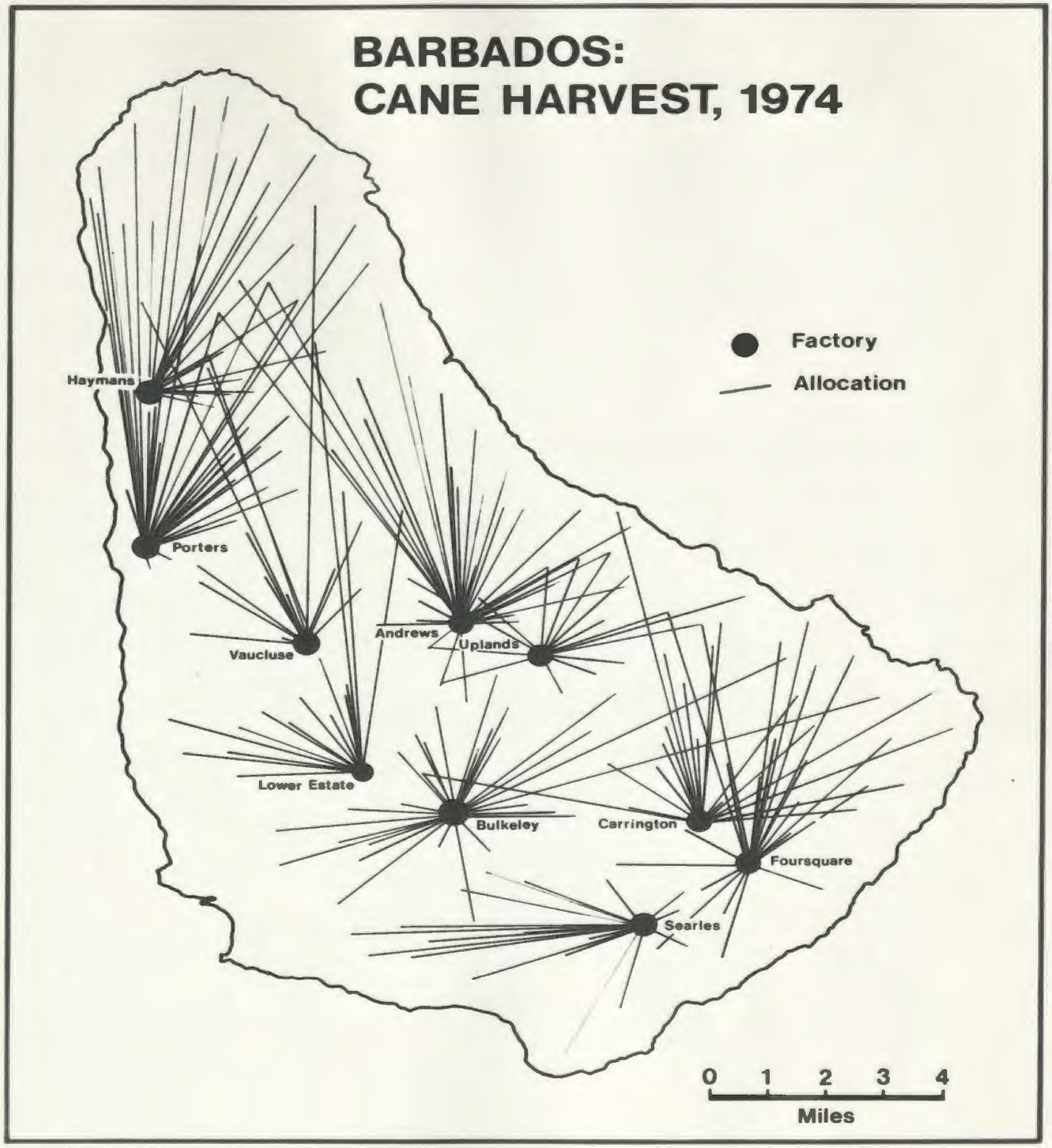
Factory	1973	1974	Grinding Rates (Tons of cane/hour)
Foursquare	102,420	129,600	60
Guinea	55,580	-	30
Haymans	123,300	123,300	48
Lower Estate	98,000	108,000	50
Porters	110,800	118,800	55
Searles	97,700	108,000	50
Uplands	89,400	103,680	48
Vaucluse	94,600	103,680	48

A. Primal Solution

The transportation costs for sugar cane movements for this year were calculated from the normative solution as being $2,469,711.80 at maximum efficiency. This represents an increased cost of $58,834.95 or 2.4% over the minimum total cost for the same crop for 1973. This is an entirely expected increase since the elimination of two factories would obviously cause higher individual and total costs. The surprising factor is that the difference is no greater than it is. Figure 13 shows the new allocation patterns and can easily be compared with the previous arrangement (Figure 7).

Generally there are longer flows than before and a higher average distance between farm and factory. The longest occur between Lamberts and Vaucluse, Crab Hill and Porters, Richmond Hill and Vaucluse and Cleland and Lower Estate, all of them being associated with farms in the north of the island. In contrast there are only two long hauls for the rest of the island with Golden Grove and Palmers estates being routed to Bulkeley factory. There are generally longer flows in the north compared to the south. This is

Figure 13


BARBADOS:
CANE HARVEST, 1974
Factory
Allocation
Haymans
Porters
Vaucluse
Andrews
Uplands
Lower Estate
Bulkeley
Carrington
Foursquare
Searles
0 1 2 3 4
Miles

not a surprising find since the removal of Fairfield tended to imply that flows from those areas, once serviced by this factory, would be somewhat longer than others. It is also expected, since the removal of a factory from the north, which is already sparsely distributed with factories, would have more impact than the removal of a factory from elsewhere. The entire allocation pattern has shifted southwards.

Secondly there are far less split allocations than there were for 1973 and for 1974 there are no farms which are being allocated to three factories as happened before. It is important to note however that where these double assignments are made in the program, they occur usually in the southern section of the island where there are more factories in close proximity. The explanation is fairly obvious. With less factories close together fewer plantations and peasant farms can view more than one factory as economically sensible alternatives for the sale of their canes. The north-south difference in this respect lies in the fact that seven of the ten remaining factories are located in the southern sections of the island compared to three in the north. As a matter of fact Vaucluse could be considered more as a centrally located plant, rather than being in the northern parishes proper.

B. Dual Solution

1. Equilibrium Prices

The equilibrium prices at the factories for 1974 were as shown in Table 5 below.

TABLE 5

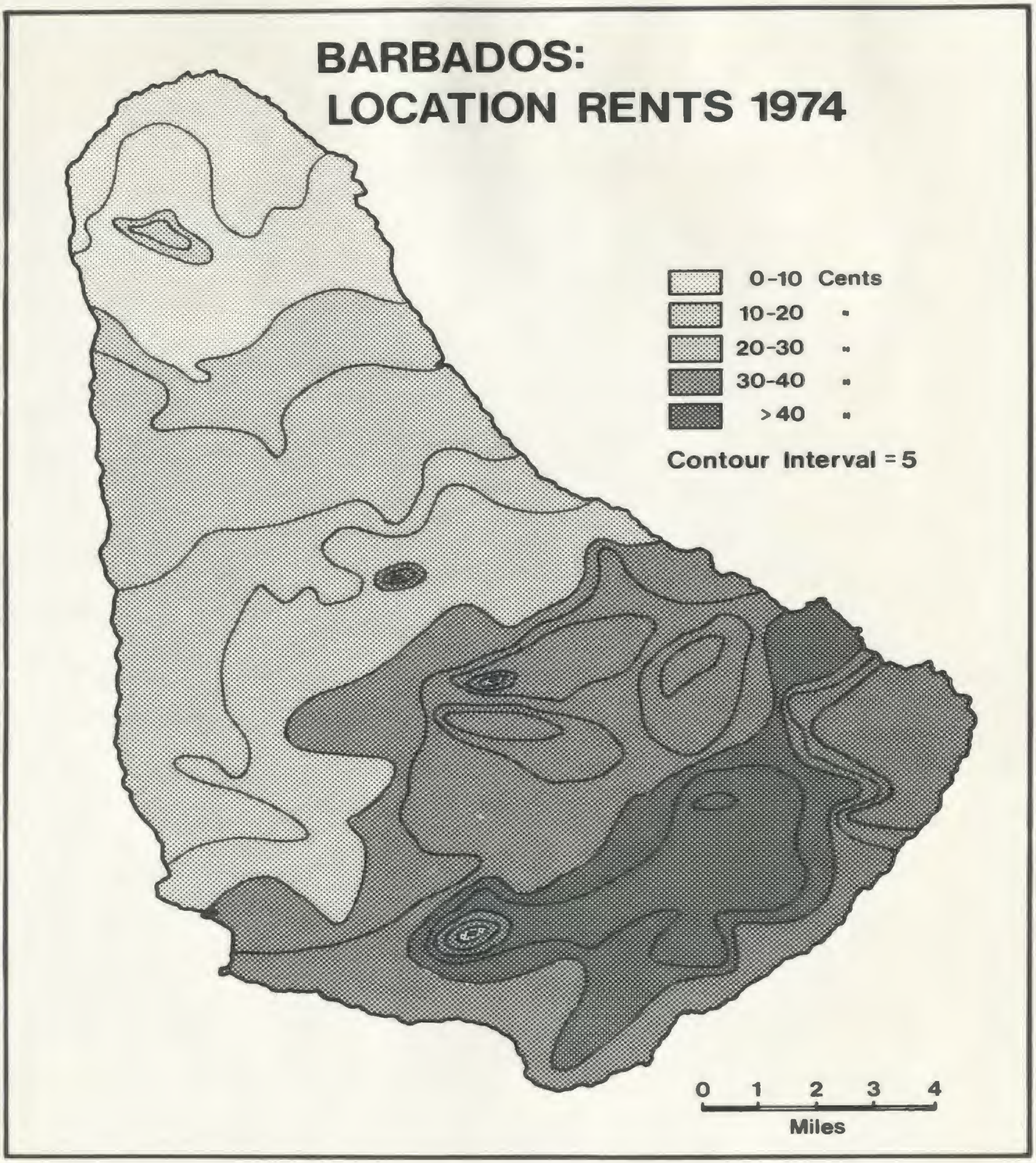
Andrews	196	Foursquare	197	Porters	189	Vaucluse	192
Bulkeley	195	Haymans	179	Searles	213		
Carrington	204	Lower Estate	197	Uplands	208 (cents per ton)		

There has been a general increase in the prices at the factory yard and this is due to increasing distances and so a greater value added because of extra transportation costs. This is a general statement which hides some significant internal differences. The equilibrium prices of all the northern factories have fallen - Vaucluse by three cents, Porters by nine cents and Haymans by ten cents. Two have remained stable at the same price of 196, those being Andrews and Lower Estate. All the others have registered increases - Foursquare, nineteen cents; Searles, eighteen cents; Uplands, seventeen cents; Carrington, nine cents; and Bulkeley, five cents. This seems to be due to the fact that the entire structure is an interlocking system of rents and prices connected by transport links for the whole island operating as one unit. The removal of a northern factory has created greater locational disadvantages for farms in this zone because of the longer flows seen in the primal solution. In an interlocking system, the marginal areas are marginal not only with reference to a particular factory, but for the entire structure. Since (V_j) equilibrium price is the value of transport costs plus location rents, the creation of higher rents because of the closeness of many factories in the south has at the same time resulted in higher prices at the factories. This is precisely Stevens' point in viewing V_j's also as location rents.

2. Location Rents

For 1974 there is wider range in the rents from zero to forty seven cents compared with a highest of eighteen cents for 1973 (Figure 14). There is a whole shift southward of the centre of the rent surface. Generally there is a regular pattern from the zero rent farms in northern St. Lucy and gradually increasing into the central zones almost uniformly from west to east. The system merges into two peaks southwards. The first high rents area lies around Uplands with rents in the high thirties and forties including such

Figure 14


BARBADOS:
LOCATION RENTS 1974
0-10 Cents
10-20 "
20-30 "
30-40 "
>40 "
Contour Interval = 5
0 1 2 3 4
Miles

farms as Ashbury, Henley, Todds and Ellesmere among others. From here there is a lower rent trough around sections of St. George in the estates Fairview, Farm, Drax Hall and Cottage with twenty six cents. It then builds up rapidly to the second high zone around Carrington, Foursquare, and Searles factories. This is essentially the St. Philip parish and its adjoining sections with Christ Church, St. John and St. George. The highest rent farms are Sunbury, Edgecumbe, Carrington estates and Oughterson along with a few others. To the east of this lies a lower zone of rents around twenty nine cents. Again as was the case in 1974 the worst areas are in St. Lucy and St. Andrew and the coastal areas of St. Peter, James and St. Michael. The best rent zones are grouped around the seven southern factories particularly the southernmost three. The localized lower rent zone of this region occurs in that area once served by Guinea including Moncrieffe, Cliff and Society estates. The northern low rents are a reflection obviously of the removal of Fairfield from the system. Note that because of this Morgan Lewis, the most marginal farm for 1973, now has a rent of fourteen and the zero rent farms are Checker Hall, Friendly Hall and Crab Hill to the north. There are a few anomalies. Bannatyne is again a low rent farm ten cents in a high rent zone as is the case of Golden Ridge, twenty six cents. At the other end of the scale is Mount Wilton estate with a very high rent, forty two cents, located in a region of generally lower rents. There is another interesting case in the north where Bourbon and Alleynedale earn rents of eighteen in a zone usually yielding advantages of eight cents or less. This is due to the fact that the optimal allocation for them within the total system is to Haymans factory while most of their neighbouring farms go either to Porters or Vaucluse, both of which are further away. It is by now evident that the removal of Fairfield from the system had a greater impact on costs and rents than did that of Guinea which was in the main factory zone. Thus the old Guinea farms are an anomaly in a highest rent area, but yet earn much more than the Fairfield zone or most of the northern area for that matter.

While there have been important changes in the two rent systems for the two years yet the basic patterns are somewhat similar. The major high rent zone for 1973 is also part of one high zone for 1974 though this is not a very close fit and the second peak for 1974 does not coincide with any 1973 best location zones. This could be somewhat misleading since the rents and their designation as being high, low and so on are relative to the situation for the particular year. The range has expanded so that areas of lowest and medium rents for 1974 now gained around twenty cents which would have been highest for the previous year. In a sense they are better off financially compared to their worse located neighbours whose relative positions worsened. The classification is therefore arbitrary since a farm which can earn a rent of anything over zero is doing fairly well and a rent of twenty cents is very good even though others might be earning forty seven cents. The classification is for comparative purposes only and marginal farms except for the zero rent ones, are disadvantaged only in respect to others better located than themselves.

3. Marginality

With a stable ecological base and a shifting rent surface the relationships between the two and the resultant total marginality boundaries have shifted for this year. There is now no clear cut relationship between good production zones and advantageous locations in the rents sense of the word. For example the high rent zone in the south around Carrington, Foursquare and Searles factories are in the two worst ecological groups. On the other hand the rent zone around Uplands with its peak, is in one of the best ecological categories. The best fit occurs for the mass of farms in a sort of middle zone which coincides with good ecological groups and reasonably high rents.

This approximates to rents of thirty and yields of around thirty two tons per acre. For this year the best farm is Clifton Hall with highest rents and highest yields. There is again however a quite good relationship between the areas of both low rents and low yields. The St. Lucy, Andrew and coastal regions of St. Peter, James and Michael again emerge as zones of greatest marginality in a composite sense. This is also true of the area in southeastern St. Philip with low yields and low or medium rents. There is still a lot of validity in talking of total marginality for the sugar industry. It can still be said that the 1974 pattern reinforces the 1973 one to the extent some marginal areas have become worse off.

However the fact that the best areas at both levels do not coincide tends to suggest that the present ten factory system is not the best organized taking into account the highest yielding farm regions to be serviced, and implies the possibility of reorganization. This is, of course, assuming that it makes more sense economically to have factories nearest to the major producers. It is reasonable to make that assumption, since with the coincidence of best land and best factory locations the bulk of any harvest would have shorter distances to move and so incur lower costs. What emerges would be a balance or trade off between the overall good and individual disadvantage, which can be easily offset by a subsidy or preference if necessary. While it is economically unsound to relocate expensive factories merely to improve transport costs, there are many reasons dealt with in the next chapter which suggests that relocation is feasible and necessary for further factory rationalization in the Barbados Sugar Industry.

C. Conclusions

The 1974 results have shown how the system of allocation, rents and prices have been altered because of one factor changing. There are two other parameters in the model which can also cause change in eventual solutions, these being transport costs and farm production changes. The first can be caused by a switch to new methods of harvesting and transportation as in the recent introduction of chopper harvesting which used special bins on the trailers. Farm outputs can increase due to new varieties of cane, a change in acreage between food crops and cane on estates, or any similar factors. Since the final result is so sensitive to peculiar combinations of these crucial factors there is a point to be made on the use of the model. Results obtained are optimal only for a specific and fairly limited time period over which drastic changes are not expected. For planning purposes this period is usually one year which is also the best planning period for a cane harvest, and if this method were ever used new solutions would have to be found on a yearly basis.

V. RATIONALIZATION OF THE FACTORY SYSTEM

A. Evolution of the Factory System

The allocation models used in previous chapters create efficiency within the context of an existing infrastructure, which is not necessarily the most efficient form of organization possible. It is thus a purely short term solution given the structure of the present arrangement and any weaknesses inherent in that system. This is exactly what was done through the use of the twelve and ten factory structure for the Barbados Industry. However there seems to be clear evidence to suggest that the present pattern could be improved by a reduced number of factories, but carrying larger grinding capacities and throughput. This chapter looks at the issue of factory centralization and the need for a more rational system, particularly the locational and allocation aspects of this change.

The factory system in Barbados evolved over a 300 year period beginning in the 1640's with the introduction of the first mills from Brazil. Gradually as each estate got organized, it developed its own processing equipment which worked year round to produce sugar for the overseas markets. By 1708 there were 485 mills of which 409 were wind driven. The first steam plant was introduced in 1840 and at this time there were 506 windmills. The steam plants were more efficient particularly with the introduction of vacuum pans, a centrifuge and horizontal mill, so that by 1895 there were over 100 steam operated factories. Concomittantly there was a sharp decrease in the number of windmills and in 1900 there were only 338 left.[1] By 1913 these had again reduced to 217 with a slight increase in steam factories to 103. The

[1] Notes on Barbados Sugar Industry, PAM. West Indies Sugar Technologists Meeting, May 1973.

first World War and a higher demand for sugar saw the first large factories being built. In 1929 twenty-nine centrals were in operation and a small residue of steam and wind mills. In 1939 following an inquiry after the years of social unrest a survey listed thirty three central factories, thirty seven wind mills and thirty five steam plants. The last wind mill at Morgan Lewis ceased operating in 1946 and by the 1950's there were only ten steam driven plants and twenty four large factories.[1] This process of change and amalgamation went on into the 1960's with a further reduction to sixteen factories (centrals) and six steam operations making fancy molasses. In 1970 one more sugar factory and four steam plants were closed. The latest episodes in the changing factory structure are going on now in the 70's. In 1970 there was the consolidation of all remaining factories under a single management authority, The Barbados Sugar Factories Limited. As a result of this change three factories and the other steam operations were immediately closed while a larger factory, Guinea, was converted into a fancy molasses plant. The 1973 harvest was processed by twelve remaining factories. Before the 1974 crop two other factories, Guinea and Fairfield, were listed to end grinding operations.

B. Centralization

The debate on centralization of the factory system has gone on in the island for well over a hundred years. First serious mention of the issue was in 1885 when a bill was passed in the legislature allowing the Barbados Agricultural Society to raise the necessary loan for a central. The whole idea was squashed, however, when good enough security could not be given by the planters against the debt. In 1898 two financiers from Britain made proposals for the building of a central. The arrangement was to be that cane

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[1]Saint, op. cit., 5.

growers supply them for ten years at a price not exceeding 10/- per ton. Besides, the planters were to receive half of the factory profits after all relevant expenses had been deducted, including the sinking fund and depreciation. This profit was estimated at one shilling and three pence per ton of cane giving the plantations a total earning of eleven shillings and three pence per ton of cane. The planters, however, calculated that they were earning twelve shillings six pence per ton of cane for the manufacture of muscovada sugar and choice molasses using their own small plants, and therefore rejected the proposal.[1] The issue was carried over into the following century. In 1908 moves for the creation of a central were introduced into the House of Assembly. It was pointed out that

> So long as the present market for muscovada sugar existed, the necessity for sugar factories was not apparent.[2]

The caution was given that the muscovada trade was unstable and could easily crash, and that new factory machinery was capable of a greater juice extraction than the old mills, which only removed about fifty six parts of juice per 100 parts of cane. The considered opinion of the committee was that serious efforts should be made to raise the necessary capital for such a factory. At this time however the building of centrals in Puerto Rico left Barbados in a more favourable position to supply North America with molasses. This was particularly evident after 1905 when a new process was discovered by which "fancy molasses" was made. The island's advantage arose from the fact that the new conversion process could more efficiently be carried out in small plants rather than large factories, and so the island filled the gap left in the United States market by the factory changes in Puerto Rico. As Sir John

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[1]Saint, 1953, 5.

[2]Official Gazette, July 26, 1909. Documents laid before the House of Assembly, May 6, 1909.

Saint puts it:

> All the evidence goes to show that until the first World War improvement of factories was a slow process in Barbados and the chief reasons were undoubtedly the demand for edible molasses which could be sold above the parity of sugar and the difficulty of finding capital for such improvements.[1]

Within the last decade the issue has again risen, particularly at this time when reorganization of the industry seems so vital for its survival. In 1962-63 there was a commission of Enquiry into the Barbados Sugar Industry and high on the list of potential and necessary changes was the centralization idea. It should be noted that varying degrees of centralization and consolidation have been going since the earliest debate on factory efficiency around the island. The commissioners stated the problem as they saw it:

> The proliferation of small factories and the close proximity of more than one factory to those cane suppliers who are not share holders of estates, have resulted in keen competition for cane.[2]

From there it was a short step to make the basic recommendation.

> The only solution is to have more modern and large factories strategically placed over the island so as to make it uneconomic for a grower to supply canes to more than one factory. Each factory would therefore have a somewhat monopsonistic position.[3]

In contrast to this the Sugar Producers Association does not accept the idea of total centralization. To them it is too costly a venture and a waste almost, since they have factories which are still in working condition. It is also claimed by the Sugar Producers Association that the island's road system is too narrow to accommodate larger transport units which would be

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[1]Saint, 1953, 4.

[2]Farley, R.; Ifill, M. and Brown, J., Commission of Inquiry into the Barbados Sugar Industry, Barbados Government Printing Office 1962-63, 39.

[3]*Op. cit.*, 39.

needed to supply the centrals from the estates. They admit however that some form of change is needed.

> At present there is really no coherent policy of closure and there have been a number of examples of factories installing new and expensive equipment only to go out of production a year or two later.

Their idea of change is to work from the present system and reduce the number to a desired amount based on the better ones in existence at the present.[1]

There is a lot of supporting theory behind the idea of centralization and large plants, most of it being related to economies of scale. Generally the cost of industrial products is lower in the larger plants since the costs of equipment, construction, land and labour do not vary in direct proportion to changes in plant size.

A United Nations survey on the subject lists two types of scale advantages, technological and economic. The former are derived through division of labour, process integration and the physical and mechanical advantages of large size. This operates partly through the use of machinery which is not feasible at lower output levels. Economic scale advantages operate through research, marketing, maintenance and the possibility of easier credit. Here less overhead is required per unit of output since fixed costs can be spread over larger amounts of product.[2] R. Auty has shown that the cost per ton of installed capacity for a sugar factory below 9000 tons is twice that for a 22,000 ton plant. There are also large savings to be made on factories up to 36,000 tons. One reason cited is the fact that machinery costs increase in proportion to the surface area of materials used, while capacity rises in proportion to the volume. This is particularly evident in production processes

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[1] Hudson...13.

[2] Industrialization and Productivity, Bulletin 8, United Nations, New York, 1964, 53-61.

as is sugar manufacture where the machines used are mainly containers.[1] It is also expected that larger more modern equipment will give an improved recovery ratio of sugar from sugar cane.

The concept of increased size and efficiency has been supported by Saint. In his work he evaluated the impact of many variables including rainfall and factory efficiency on the output of sugar in the Barbados Industry for a period of 100 years. He first plotted output in five year averages against rainfall for the same periods, to test the relationships and then excluded the impact of variable rainfall by calculating the average tonnage of sugar in each five year period per inch of rainfall. The increases over time were then explained by other variables particularly factory efficiency. The article showed that between 1855 and 1869 the average yield of sugar was 810 tons per inch of rainfall and this could have been increased to 1340 tons if factory performance had been equal to that of the 1940-50 period.

> The increase in production due to improved factory efficiency is that of the order of 530 tons of sugar per inch of rainfall.[2]

It seems therefore that centralization should be the next logical step in further rationalization of the factory system. Credence is added to this by the fact that the Farley Report and nearly all its recommendations, except the changes in land tenure, have been accepted by the Barbados government and included in their master plan for the long range physical planning of the island.[3] This would help to bring the island into the mainstream of rationalization at the factory level which has been going on in the other sugar

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[1] Auty, R.M., "The Sugar Industry of Demerara 1930-65, Some Problems in Identifying Scale Economics". Journal of Tropical Geography, 34, 1972, 8-16.

[2] Saint, op. cit. 5.

[3] Physical Development Plan for Barbados, op. cit., 16-17.

producing islands of the Caribbean in general and the West Indies in particular (Table 6).

TABLE 6

Number of Sugar Factories Operating

Island	1958	1959	1960	1961
Jamaica	20	20	18	18
Guyana	12	11	11	11
Trinidad	6	6	6	6
Barbados	19	19	17	17
St. Kitts	1	1	1	1
Antigua	1	1	1	1

Source: Farley, R., et. al., Commission of Enquiry into the Barbados Sugar Industry 1962-63, Appendix.

The allocation and location implications of centralization are based on the recommendations made to the government by the Farley Report. The report suggested the eventual creation of four centrals within the decade 1963-73 each with a capacity of 40,000 tons of sugar annually. It was suggested that because of financial need, two should be first built in areas with the replacement of the smaller and older existing plants in mind. The completed system should have been in operation by 1973 at which time total capacity would be equal to national production. In the location decision:

> ...the new centrals should be so located as to make it uneconomic for all but a few suppliers of cane to view any two of them as alternative outlets for their products.[1]

[1]Farley, et. al., 1962, 36.

The final system, it was stressed, would create an estimated savings of $11.08 per ton of sugar.[1] It would allow all costs and interests on the venture to be repaid within eleven years, and leave the industry far better equipped to meet possible changes in the international position of sugar.

The arguments given, particularly those of the Farley Report, suggest the need for the creation of a more highly centralized system of factories than there is at the moment. Assuming a four factory system is required, there is now the need to find the optimal locations for the factories and also the optimal allocations between the farms and the new centres. This is done by the joint location-allocation algorithm using the four factories and their capacities, and the output of the surrounding land as the basic data.

C. Location-Allocation Methodology

The programming technique used to solve this problem was developed by Cooper[2] and Miehle.[3] There are two fundamental principles involved.

(a) If the allocation of demand points to centres is known then the best centre locations are easily found by the use of a Weber type analysis. In other words the centre of gravity of a group of weighted points can be found.

(b) If centre locations are known and fixed optimal allocations can be found by routing each supply point to its nearest receiving centres. The actual algorithm divides the sources into a desired number of subsets based on weights and centre capacities. The optimum single location is then found for each subset. This is in turn followed by a number of program iterations alternating between location of centres and allocation of sources to them until stability is reached. Stability occurs when all sources are assigned

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[1] Farley, op. cit., 43. (Based on total cost of sugar production.)

[2] Cooper, L., "Heuristic Methods for Location-Allocation Problems", SIAM Review, 6, 1964, 37-53.

[3] Miehle, W., "Link Length Minimization in Networks", Operations Research, 6, 1958, 232-43.

to their closest centre, and each centre is at the minimum point of its set of demand points.

This location allocation procedure has been programmed into computer package format in a program called ALTERN devised by L.M. Ostresh. It is a program written in IBM FORTRAN language, and can be solved on a 370 computer. It is a heuristic which means that the final solution is worse than the absolute optimum and the margin of error has been calculated as being 2% above the optimum.[1] The output gives both the allocation of demand points, and sets of locational coordinates which show optimal factory locations.

D. Results: Locations and Costs

A four factory system was suggested by the Farley Report. Figure 15 shows the optimal locations of these factories. Figure 15 shows the optimal locations for a four facotry system as suggested by the Commission of Inquiry. Assuming the same outputs and transport costs as for 1973 and 1974 the allocations show a cost of $2,560,867.48 (EC). This cost is an increase of $91,155.68 or 4% over the old system. This is not too large an increase to pay in transport for an improved system. Usually centralization involves a trade off between increased transportation costs due to longer distances to travel, and the benefits from the improvement itself. The benefits have been calculated as creating a savings of $11.08 on every ton of sugar.[2] This obviously outweighs by a great margin the extra 4% transport costs which only means on the average about $2.08 a ton of cane. Besides there is also a benefit in transport costs at another level. With far less factories and these optimally located there will be a lower total

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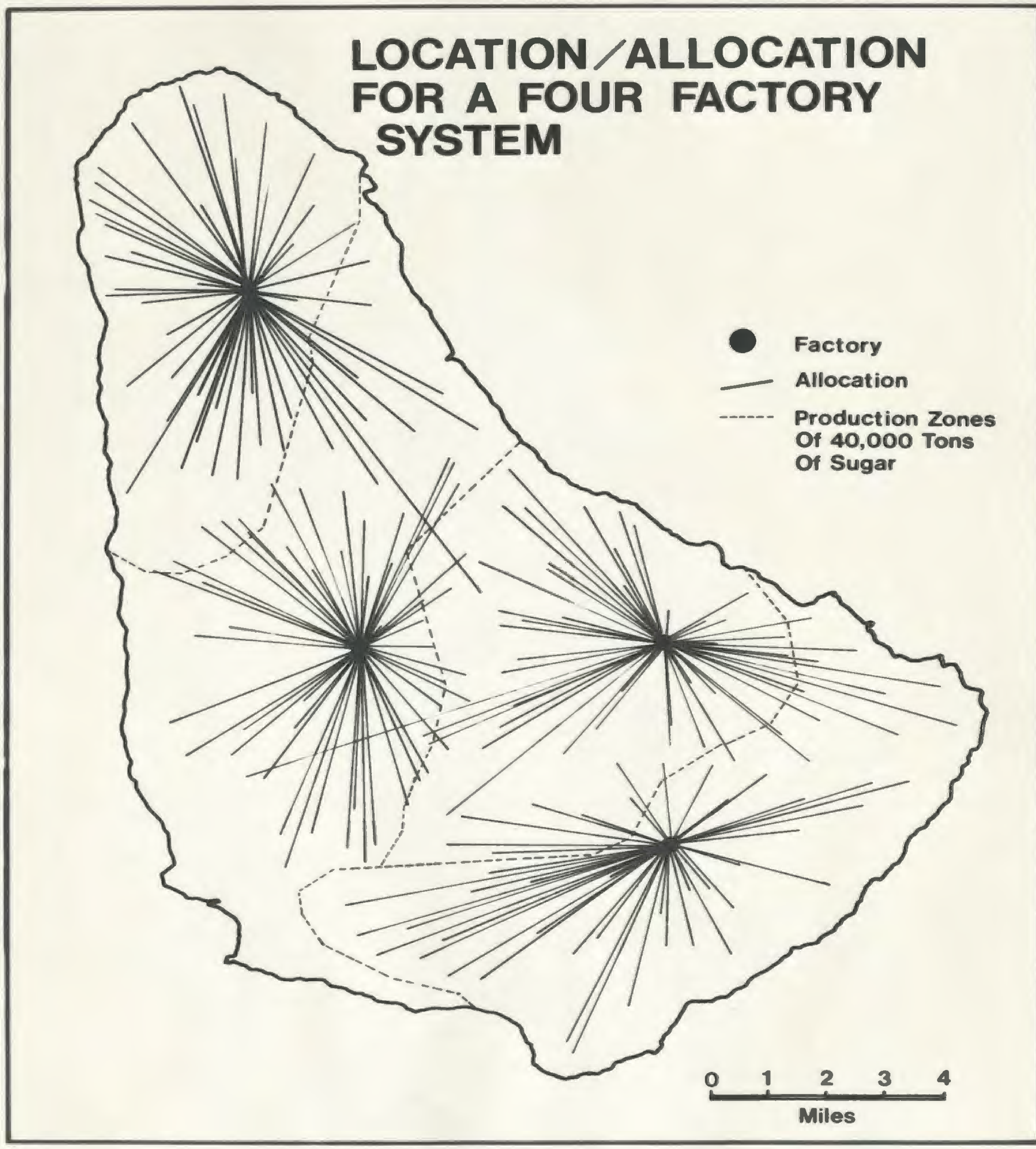
[1]Ostresh, L., Altern: Heuristic Solution to the M Centre Location Allocation Problem; Computer Programs for Location Allocation Problems, Monograph No. 6, Department of Geography, University of Iowa, Rushton, Ostresh, Goodchild (eds.) 1973, 55-66.

[2]Farley, op. cit., 36.


LOCATION/ALLOCATION
FOR A FOUR FACTORY
SYSTEM
Factory
Allocation
Production Zones
Of 40,000 Tons
Of Sugar
0 1 2 3 4
Miles

costs for the transportation of sugar from the factories to the sugar terminal in Bridgetown, the port of shipment. This has extra significance since the cost per ton for sugar is $3.08.[1] It can be concluded from these costs that the new factory system has many benefits to add to the industry and can easily offset the extra cane transport costs involved.

A further breakdown of the new cane transport costs show that of the total, peasants pay 17% and estates 83%. This is also more or less the exact ratios for each cane sector in terms of output of cane, peasants contributing between 18 to 20% yearly. The new system therefore does not discriminate between the two sectors in terms of creating extra costs disproportionately and rather favours the peasants somewhat.

A look at the map of new locations compared with the old factory system has another potential value. As noted earlier the rationale of the Sugar Producers Association is to work towards an improved system of factories based on the existing one, rather than the creation of a totally new complex. In this context it is very interesting to note that the new factories are, in nearly all cases, extremely close to some of the old factories. This is true for three new locations which are very near Vaucluse, Carrington and Foursquare, and the third factory close to Guinea and Uplands. The exception is with the northernmost factory which is not close to either Haymans or Fairfield. This means that a new factory system could be created using as a base the present factories which are closest to the optimal locations. Improvement in Vaucluse, Carrington and preferably Uplands, which seems to be more efficient and certainly larger than Guinea, could therefore be a new base of up grading for the present structure. This does not seem too difficult since all the present factories operate at a fairly close level

[1]Files supplied by Sugar Producers Association.

of output and scale, there being only thirty tons per hour grinding difference between the largest and smallest factories now operating. Additionally, the allocation system used often sends more cane to some of the smaller factories than to those with larger capacities showing that for the present structure, size and output at the theoretical level is not the sole criterion for allocation. For example, Searles factory with a capacity of fifty tons per hour gets only 97,700 tons allocated to it for the 1973 crop while Uplands and Vaucluse with forty eight tons per hour capacities are given 89,400 and 94,600 tons respectively for the year. In other words the fact that Vaucluse, Uplands and Carrington do not have the largest outputs does not lessen the realism or common sense of using them as the basis for a new system of factories. There is obviously the need to build a new factory at the optimal location in the northern area where none of the existing factories are really close enough for consideration, if a really rational system is being sought out. This solution could easily satisfy the leaders of the sugar industry who are probably more pragmatic than the idealists who insist on a totally new arrangement, and at the same time still create the kind of efficiency which a new system offers, possibly at a lower cost. Of course this does involve increased transport costs, but the increase is not very much greater than the actual optimal program. In any case transport costs are not the most important consideration in the creation of a new factory system.

E. Primal Solution

Figure 15 shows the allocation pattern for the four factory system, and when compared against earlier patterns shows some definite individualities. In the first place there are no split allocations, each farm's output being sent to one factory only, thus meeting Farley's requirements. Along with this there are very few really long hauls. The only long routings are for

Blackmans estate going to the most northerly factory, when two other factories are really close to it. The other two are Peasants 33 and Peasants 34 which go to factory three while factory two is closest to them. Of course in a planning situation these excessively long journeys can be eliminated by the simple process of reallocating them to a closer factory. Because of the earlier reasons each factory has a very clearly defined hinterland with only the few interruptions. This all conforms to the recommendations that each factory control a given land area having a monopsony on its supplies, while very few estates can view more than one centre as a potential market, without increasing their transport costs by a fairly significant amount. This all leads to a clear cut system far less complex than the previous arrangements, when there were many factories in operation. There is one interesting observation which comes indirectly out of the allocation patterns. In spite of the fact that each factory processes an equal tonnage of cane yet there are differences in the sizes of their hinterlands. For example the first factory (north) has a much larger hinterland than the second factory. This is because some areas are better cane land than others, the northern and eastern areas being the worst of all. Thus the varying size of the factories spheres of influence, also give some indication of the land potential at different places.

F. Dual Solution

This is also supported by the dual solution's equilibrium prices at the factories.

Factory one	217
Factory two	198
Factory three	217
Factory four	200 Cents/ton

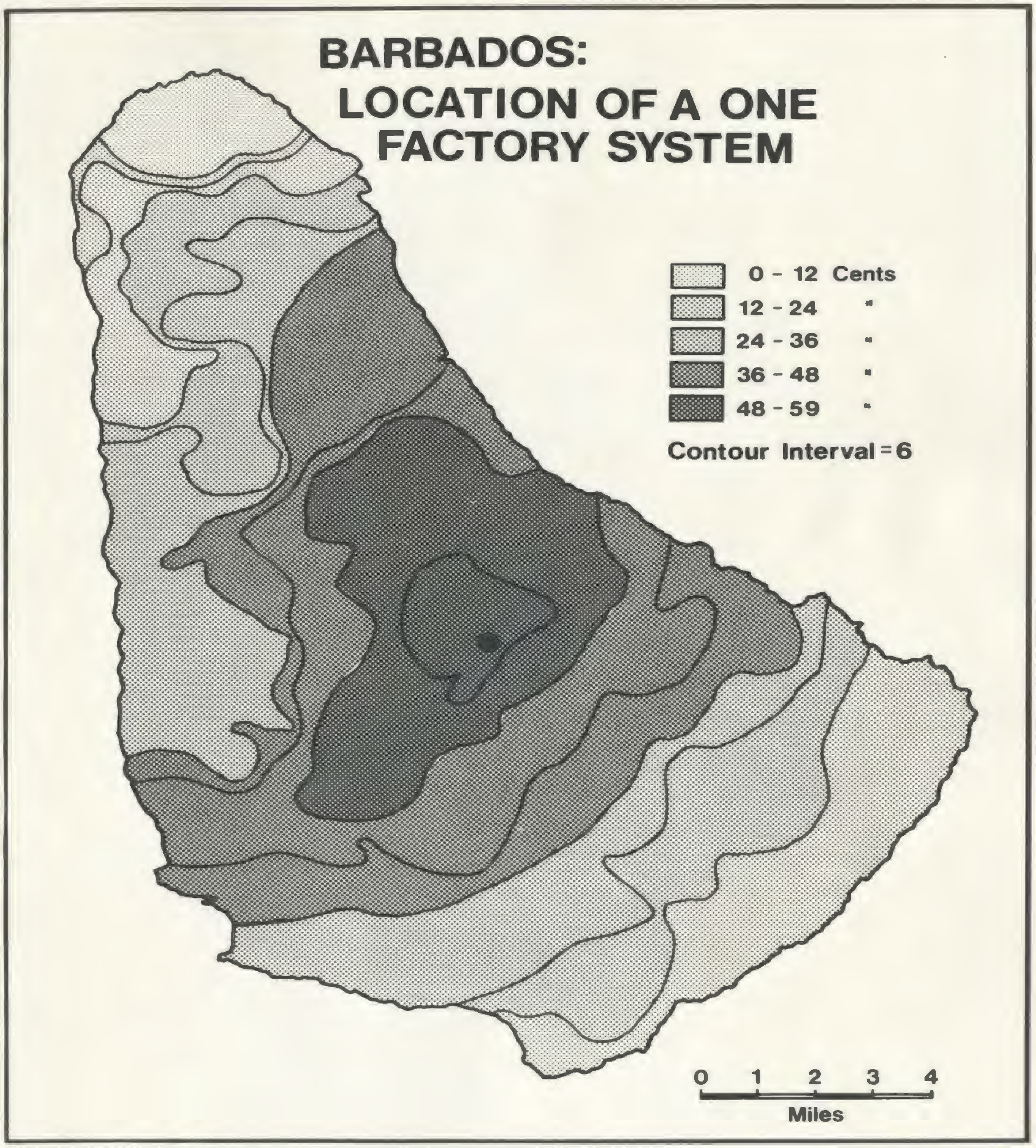
Note that the factories with higher delivered prices are the ones with larger hinterlands and also the worst farming land for sugar cane production, and while they all take in the same quantity of canes, yet their is a wide variation of price between some of them. Associated with them are the location rents on the surrounding estates and peasant farms. In this case there can, however, be little comparative meaning attached to the dual values. This is due to the fact that each factory has an independent subset of farms and there is no interlocking system of rents and prices as in earlier solutions. Each set of rents show a gradual falling off from the centre (factory) outwards to the periphery in a regular fashion. There are therefore four rent surfaces in this case and it is impossible to look at advantage and marginality in the same way as before.

G. One Factory System

The ultimate in centralization at least at the theoretical level is the creation of a one factory system. It is quite obvious that this is a fairly impractical solution taken against the background of what are supposed to be optimal sizes for sugar factories in general and Barbados in particular. Among the disadvantages associated with such a system, would be the relatively long hauls involved in transporting the cane from the outer estates to that centre, and the possibilities of congestion at the factory yards and on the roads, with long queues of loaded trucks awaiting service. Yet the idea raises a rather absorbing question of both theoretical and academic interest which is satisfying to answer. In a geographical context it becomes a pure location problem. Given the spatial arrangement of producing units and their varying outputs, where could one factory be located,, so as to be sited in that precise spot most accessible to all the producers? Immediately there are echoes of the type of methodology and problems dealt with by Weber, and Lösch who are really the fathers of most industrial location theory. This problem was solved using ALTERN particularly its Weber Subroutine program, Figure 16 shows the result. The centre of gravity of the weighted distribution of all sugar producing land in Barbados was found to be an area midway between Uplands and Andrews factories. From the location decision a series of location rents were calculated for the island. It shows convergence on the centre and a very regular fall off on all sides until the margins are reached. It is interesting to note that the worst located areas, with zero rents or little more than that, are again found in the northern sections of the island, coinciding with the areas of worst farm land. The highest rent areas again coincide quite well with the areas of most fertile cane land, except in a few areas on the edge of the Scotland area which have very good locations and poor ecological conditions. This again is not a surprising find. In using weights based on productivity in both the four and one factory cases, there must be a locational bias in favour of the better lands getting best locations relative to the factories. This is good also for indicating the areas which could soonest be eliminated in any retraction program for the industry.

The results from the centralization processes tell something of the locations of the present factories. Uplands factory is always close to some of the new locations as was seen in both the four factory and the one factory system. It seems unlikely to be merely coincidence since the location decisions are based on important factors relating to the industry. There seems to be grounds for assuming that Uplands is the most strategically located of all the factories in Barbados. Other well located factories in terms of present and future needs are Vaucluse, Carrington, and Foursquare. In contrast the worst located are Porters and Haymans. Even in the earlier allocations, Porters was always the factory to get any extra unused capacity left to it in the computer solutions, underlining the fact that in the total system it is

Figure 16


BARBADOS:
LOCATION OF A ONE FACTORY SYSTEM
0 - 12 Cents
12 - 24 "
24 - 36 "
36 - 48 "
48 - 59 "
Contour Interval = 6
0 1 2 3 4
Miles

most disadvantageously located. This factory, along with Haymans, is again worst located with reference to a new four factory system and also the single factory, being farthest away from the new locations. There is therefore the possibility that all other things being equal these two should be the next two to be scrapped in any program of change. This kind of realization can also be of benefit to the industry which sees a gradual change and phasing out of some factories as being the most practical and least costly solution. Haymans also happens to be one of the remaining factories which has the lowest grinding capacities being forty eight tons an hour. An incidental point of interest comes out of the smoothness and regularity of the iso-profit lines. These are determined on the basis of distance measured in road miles and costs which are directly proportional to distance. The regularity therefore suggests that the road system exhibits an almost equally dense network all over the island.

VI. EVALUATION OF THE STUDY

A. Assumptions, Data & Results

In the foregoing chapters an analysis was made of some aspects of the Barbados Sugar Industry, specifically the location and allocation decisions as they related to the transport of canes to factories, and factory organization itself. There were two distinct though related processes under consideration, one being a short term goal while the latter involved the longer range planning of factory facilities. The short term solutions sought to find the most efficient allocations of farms to factories for the two years 1973 and 1974, using the present factory system and prevailing levels of farm output and transport costs. From this initial starting point the scope of the study broadened to look at the historic processes of amalgamation in the factory complex and its present levels of efficiency. The conclusion emerged that the present structure could profitably undergo rationalization through the creation of four modern strategically located centrals which would replace the small and in many cases ageing plants now being used. Some of the main conclusions reached were:

(a) The industry was presently operating at a very high level of efficiency in its scheduling operations, but a more objective approach to the allocation decisions would create increased savings in transport costs.

(b) Locational advantages for specific areas and farms tended to be similar at both the agronomic as well as the transport cost level, creating a core area most suitable for sugar cane production based on both yields and savings in transport costs.

(c) Spatial changes in the industry could be easily monitored and controlled, and a planned retraction of the margin of cultivation from the periphery inwards to the core area implemented, if necessary.

(d) A pattern of optimal factory locations could be and were found, taking further rationalization of the factory system into account, while at the same time selecting the optimal allocation of farms to these new centres.

The solutions were found with the use of linear programming techniques specially programmed for computer application. While it is true that the technique seems to be most admirably suited for the type of problems dealt with, there are a few attributes which must be borne in mind which might have lessened the effectiveness of the results. This method assumes the linearity of the relationships in the program; in this case that costs are linearly related to distance and can thus be plotted on a graph as a straight line. Dorfman, et. al. asked a valid question generally concerning linearity:

> Can economic problems be cast in this strict format without doing them mortal violence?[1]

In this case costs and distances are effectively linearly related. This is because there is a regular increase in cost per unit distance and there is no distance (Figure 6) decay function involved. Thus the constraint of linearity holds for the study. Secondly linear programming provides a non-dynamic and short term solution. In other words the result is very sensitive to the input data and factors operating outside the rigid formulation of the problem are not explicitly taken into account. For example in the location decision a factor was left out which could possibly have affected the result. Usually location of an industrial plant is viewed as an equilibrium of different classes of influences, raw materials and markets being the two most important. Our model took only the raw material, sugar cane, into consideration and the locations were based on the farm lands without thought of the movement of

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[1]Dorfman, et. al., op. cit., 8.

sugar from factory to the sugar terminal in Bridgetown for eventual shipment overseas. However there are grounds for suggesting locations away from the port. There is a material index of nine for sugar cane, and this in Weberian terms suggests location with reference to the raw material source, in this case cane fields. The terminal and port are already located in Bridgetown, the primate city with all its associated problems of traffic flow and congestion without numerous cane transport vehicles adding to the difficulties. When put against the background of noise and smoke which is typical of a sugar factory, then the omission has justification. This is not to say that market attractions are not important in location decisions, but in this case they seem worthy of subordination to other factors. This failure to take into consideration in any serious way other factors particularly the dynamic and unpredictable is evident in the allocation decisions. One of these omissions is the impact of incendiary fires. In recent years there has been a spate of unauthorized fires which invariably burn much larger acreages than can be easily fitted into the normal grinding schedule of the factories. As a matter of fact each producing unit is given a weekly quota to send to the factory to keep operations running smoothly and as near to full capacity as possible. When there is a large burnt acreage which is not in the schedule, then it creates operational stresses. In some cases in order to process this cane before it is lost entirely, factories to which it was not allocated in the first instance might be asked to help process it. Besides that, the model assumes that all the factories work at full capacities for the entire season. Any breakdown in machinery therefore can affect the whole system since it is based on output and capacities over a given period. The latter two situations are not really criticisms of the model since these occurrences are irregular and unpredictable, and cannot therefore be programmed into the problem, particularly when allocations are planned before the crop actually begins. It is really more a recognition of the fact that the full reality is so much more dynamic and complex than models which abstract reality down to the important elements only. "Strict descriptive faithfulness is an unreasonable demand to make of any conceptualization."[1]

Finally in terms of the methodology itself, the location allocation model (ALTERN) is a heuristic algorithm. This means that the solutions found are not necessarily the optimal ones. Heuristics may contain two sets of answers, a series of optima, and a global optimum. The global solution is the true optimum, while the local solution is optimal only for a particular subset of possible solutions. The problem is to ensure that the global answer is found. L. Ostresh states the problem this way:

> The problem is not one of getting the algorithm to converge... it usually does this with very few alternations...but of getting it to converge optimally, for many allocations exhibit stability.[2]

There is one method of testing to see if the solution obtained is the global optimum, and this is to run the program several times and check the result. In this case there were three runs of the program, each execution being done with a different initial allocation. In all cases the result converged around the same locations and allocations with only a .12% ton miles difference between the best and worst solutions. While there is no absolute guarantee, there seems to be logical grounds for assuming that the solution found was in fact the global optimum for this particular problem. However these are all methodological drawbacks which could not be easily overcome and could be expected, in that the formulation required a honing of the problem to the essential elements the better to analyse them. There is only one demand which can be made on a conceptualization.

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[1] Dorfman, *et. al.*, *op. cit.*, 9.

[2] Ostresh, *op. cit.*, 56.

> What we have a right to ask of a conceptual model is that it seize on the strategic relationships that control the phenomenon it describes and that it thereby permit us to manipulate, i.e. think about the situation.[1]

This, the model has done adequately, and for this reason it seems in spite of some drawbacks associated with all model usages, that it was one of the most suitable if not in fact the most appropriate tool for this type of analysis.

With the data collection procedures there are two elements which are worthy of note, one is an assumption and the other an omission. The costs which were used were calculated by W. Campbell who found an average cost for all transport of cane for the entire island. However, he showed that final costs were dependent on such factors as distance, turn around time at the factory yards, loading and unloading rates, travelling speeds and the number of trips per day. His final cost assumes that all transport operations are working at similar levels of efficiency which seems fairly unlikely. It is possible that some estates operate above or below the average. However this was the best measure of cost available. The ideal was of course to calculate the cost of each individual farm and work from that basis since most transport is done with the plantation vehicles, and not by private freighters. This is not therefore a pure transport cost since depreciation and maintenance which also help to determine haulage costs per ton are in fact spread over other farm operations for which the same transport units are used.

In the research design it was hoped to be able to use a combination of both transportation and production costs. This is quite feasible since Maxfield[2] has shown that costs other than transportation which have

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[1] Dorfman, et. al., op. cit., 9.

[2] Maxfield, D., "An Interpretation of the Primal and the Dual Solution of Linear Programming", Professional Geographer 21, No. 4, 255-263.

place to place variations can be put into the design and evaluated in similar fashion. This would have given for each farm a much more precise measure of marginality and advantage at both production and transportation levels. It could also have shown if some areas have good locational advantage in the transport cost sense partly balanced by poor performance in production, and the precise measure of the impact of one on the other. This was impossible to do since the only production cost given is a very generalized average for the entire island in which areal variations could not be discerned. This was also difficult to attain since on the farm's balance sheets, transportation costs are listed as a part of the total production costs and not a separate entity in itself. Other forms of data with spatial implication were however used, and these also allowed an accurate measure of marginality and rents. This was the use of the data on Ecological Groupings for the island's estates, which could still be combined with transportation advantages into a composite map, to show the core areas and marginal zones for the island's sugar industry. This of course involved a greater measure of subjective reasoning but did not materially impair the effectiveness of the study in this respect at all, since the identification of groups was based on all the major factors which cause differences in production costs and yields. Besides, the groups were so structured as to give a quite accurate closely bounded measure of difference between the various ecological boundaries.

B. Location Allocation Efficiences And Structural Change

This study has looked at the sugar industry with reference to certain aspects of reorganization which seem to offer potential benefits through increased efficiency and savings. It attempted to answer specific questions relating to technical aspects of reorganization in the industry, and explore resultant implications through a methodology which proved capable of answering the question. There are, however, other types of questions which must be answered, but these are not in a strict sense a part of the reorganization process dealt with. While this study cannot deal with them fully since they deserve a full treatment elsewhere, yet they must at least be mentioned and recognized. This is because they are in many ways more fundamental to the whole idea of reorganization than management efficiencies, and so help to put this work into a total perspective. There are three levels at which this work could have been viewed. There is the international level of the world sugar demand and supply situation, a local level which embraces the island as an economic unit and views the sugar industry against total development. Finally, there is the highly localized microcosmic scale of the industry itself. Though they can all be viewed separately, yet they are differing faces of one whole.

At the international level there are many related problems, the major one being competition among suppliers for certain markets. This operates through competition with European beet producers. Given that Barbados' main market is Britain, local supplies of sugar suffer from higher transport costs, due to much longer distances, the fact that the sugar beet industry is highly subsidised, and has a higher recovery ratio of sugar from beet, as compared with cane. In fact from the point of view of costs and profitability it has been estimated that between 1954 and 1964 the cost of producing a ton of sugar from cane had risen by 50%, while at the same time the cost of producing a ton of sugar from beet actually fell by about 15%.[1] This poor competitive position is becoming gradually aggravated by changing demand patterns. Traditionally a significant quantity of West Indian sugar was redistributed through Britain to her African colonies, but now with

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[1] Sturrock, F.G., Sugar Beet or Sugar Cane? Journal of Agricultural Economics, Vol. 20, 1969, 125-31.

African production gaining momentum there could be a lessening of demand for West Indian sugar. The whole situation is now being compounded by the entry of Britain into the European Economic Community. At present all West Indian sugar sales to Britain are made through the Commonwealth Sugar Agreements Act, a quota system with negotiated prices which will end in 1974. At the end of this period bargaining will obviously be much harder with the possibility of a reduction of purchases from the West Indies due to Britain's economic commitments to Europe.

At the local level the range of problems have been largely dealt with earlier (see Chapter 7). Besides the specific problems of costs, prices, arson, labour shortages and poor agronomic techniques in some cases, there is a major general problem which embraces all the others. Sugar is still vital to the island's economy, and so reorganization and the future of the industry must be always viewed against the background of its crucial role in continued economic growth. It is therefore imperative that all necessary steps are taken to revitalize this key sector if it is to continue its role as a leading industrial sector in the total economy. This immediately means that any problems within the industry itself have to be viewed within the broader framework of the island's total economy.

Even if and when the profitability of the industry has been reestablished on a solid basis, there will still be an important social problem to be solved. This is the problem of ownership and control of the industry. At present there is a very skewed distribution of land ownership on the island with four fifths of the cultivated land being owned and operated by approximately two hundred and forty estate owners. The rest is cultivated by over 18,000 peasants, many of them tilling as little as one quarter acre of cane. While it is true that fragmentation into uneconomic sized units makes no sense, redistribution can take place through larger cooperative blocks and or government farms, and even through the workers' union. This would give many more people, particularly the workers, a stake in the industry they make possible, and help to counteract the alienation from the land which is currently evident. It might also help to arrest the continuing flight of land from agricultural usage, an estimated six thousand acres having already reverted to non farm uses in the last five years.[1] What the industry needs it seems, is a massive reorganization, including a look at all possibilities and alternatives in the locational and temporal structures, and which take into account the dynamics of current local and international trends affecting it.

This work has looked at reorganization at the industry level essentially, and therefore presents a selective spatial viewpoint studied at a micro scale. Spatial reorganization will certainly not cure all the evil of the present system, but it is still an important factor in economic rationalization. The success of any enterprise obviously depends heavily on the economics of operation at any given time. Therefore, periodic appraisals are vital in all its aspects including the locational. By so doing one can judge whether the society is persisting with sub optimal structures which are largely a product of inertia, and so do not serve current needs as effectively as they should. This study has looked at patterns of flow, and locations for the sugar industry and suggested directions in which future decisions can be taken. In some instances, particularly with the issue of centralization, use was made of earlier work which might itself be questioned by some other authorities on the matter. What is really important is the approach to the solution of the problems. Through spatial allocation analysis one can view the distribution of economic flows over geographical space and the patterns of trade even at the local

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[1] Barbados Sugar Industry Review, Dec. 1973, 2.

level, which take place in specified economic commodities. In addition these models provide valuable insights into the operation of economic systems and is one of the most powerful conceptual frameworks used in modern geographical analysis.

GLOSSARY

Bagasse - a fibrous material left after the juice is extracted from cane piths by crushing. When mixed with additives it is used for animal feeds. It is also used as a fuel to fire the boilers of many factories.

Boiling House - old name for buildings on the early plantations in which the manufacture of sugar from cane was carried out.

Cattle Mills - some of the earliest machinery used to crush cane as an initial preparation to the making of sugar. The machinery was powered usually by bullocks.

Centrals - name given to large modern sugar factories with large capacities and high output levels.

Centrifuge - a machine which produces centrifugal force necessary for particular operations. In the sugar industry in particular, it is used for separating fluids in the manufacturing process.

Choice Molasses - also called treacle and is a by product of the manufacture of muscovada sugar.

Compaction - a term used to describe the process by which heavy machinery binds the soil into a hard mass more difficult for plants to survive in. In the case of Barbados this is mainly a result of the switch to mechanical harvesting.

Compith - the major component from a new method of sugar cane milling called the separation process. It contains 70-80% of cane stalks and 93% sucrose. The sugar is extracted in the separator and made into sugar and fancy molasses. The compith is then broken down into its smaller elements, pith cells and fibro vascular bundles. The fibres are then used for making soft board, hard board, pulp and paper, and the pith cells are used as a base for animal feeds and explosives or as a base material for the chemical industry.

Comrind - the second major component from the separation process. After the removal of the soluble particles by hot water the base material can be processed into laminated timber, core panels and plywood veneers.

Fancy Molasses - this type of molasses was first made in Barbados in 1905. It is manufactured by converting cane juice directly into syrup. It is a speciality of Barbados and an old well established trade in fancy molasses exists between the island and both Canada and the United States.

Furrows - small trenches made by ploughs which are then planted with cane. This method has now replaced the traditional caneholes used before, in order to facilitate mechanical planting and harvesting.

Mulching - the use of a leaf cover or a combination of manure and leaves to protect newly planted roots from dryness and heat or cold by controlling the rate of evaporation. This practice, once widespread on Barbados Sugar estates is declining in usage particularly due to fires which removes the "trash" cover with which the mulching is done.

Plantation - a large scale production operation often around three hundred acres concerned essentially with cash crops for the overseas market. In Barbados a plantation or estate is defined as a farm unit of more than ten acres of land.

Peasant Farm - a small scale unit usually producing a wider range of agricultural products than the plantation. It is defined in Barbados as being less than ten acres of land. Most Barbadian peasant farms are however geared to the production of sugar cane.

Ratoon and Plant Canes - for the start of a sugar cane growth cycle cane cuttings of desired variety are planted to produce the first crops after a growing period of fourteen months. These first crop canes are called plant canes. At the first harvest the canes are cut to the roots and allowed to spring again to produce suceeding crops. These second crops are called ratoon crops and typically ratooning is economically feasible for four years. At the end of each five year cycle the old roots are dug up to make way for new plant cane crops.

Steam Plants - small sugar factories which were powered by steam energy.

Trash - name given to the leaves (usually dry) of sugar cane plants.

Yeoman farmers - early independent (white) farmers who tilled the soil before the advent of sugar cane and the plantation system. They grew cotton, tobacco and indigo before 1640.

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