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This is to certify that the

dissertation entitled

A FINITE SET APPROACH TO
THE TANZANIA CASHEWNUT PROCESSING INDUSTRY
FACILITY LOCATION-ALLOCATION PLANNING

presented by

Hamisi Omari Dihenga

has been accepted towards fulfillment
of the requirements for

PhD degree in Agricultural Engineering

Robert H. Wilkinson
Major professor

Date August 31, 1984

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Hamisi Omari Dihenga

A DISSERTATION

Submitted to
Michigan State University
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ABSTRACT

A FINITE SET APPROACH TO THE TANZANIA CASHEWNUT PROCESSING INDUSTRY FACILITY LOCATION-ALLOCATION PLANNING

By

Hamisi Omari Dihenga

The state of the art in cashewnut handling and processing in Tanzania was reviewed, and, where appropriate, compared to other cashew producing countries.

A finite set approach was used in the development of the cashew industry facility model. Subroutines were developed to interface with a LINDO code. Sensitivity analysis designed to answer some "adaptive if" issues—namely, possibilities of changes in cashew production levels, forcing facilities into solutions, and processing facility capacity changes—were explored.

A 15% increase in predicted cashew production in the 1983-84 season resulted in no changes in facility locations, despite slight changes in routing configurations and a 7% increase in total system cost. Processing capacity utilizations—50%, 75%, and 100% of rated capacity—resulted in 9, 5, and 5 open plants, respectively, for the 1982-83 season cashew production level (32,500 metric tons). A plant capacity utilization increase from 75% to 100% resulted in a 5% increase in system costs compared with 24% and 28%, respectively, for 50% to 75% and 50% to 100 percent.

Hamisi Omari Dihenga

The model solutions provide for locations and relocations of facilities, indicating open plants in optimal solution. The model highlights some planning alternatives that may be more attractive with respect to unmodeled issues. Facility configurations, location robustness index, shipment routes, and system costs are used as criteria for facility system evaluation and elaboration. The philosophy inferred is "insight" and "not numbers."

APPROVED:

Robert H. Wilkinson

Dr. Robert H. Wilkinson
Major Professor

Donald M. Edwards

Dr. Donald M. Edwards
Department Chairman

Dedicated to Allah.

The most Gracious, the most Merciful.
The Cherisher and the Sustainer of the Worlds.
Master of Day of Judgment.
The One we worship and Thine aid we seek.

ACKNOWLEDGMENTS

I would like to thank God for guiding me in my endeavors. I would also wish to extend my sincere thanks to my brother, Mr. Kitwana O. Mohamed, who raised me up and provided me with both financial and social support through my academic life. I would also like to give a note of appreciation to my wife Zubeda, son Issa, and the Michigan State community who helped make most of my trying days seem bearable.

I also wish to express my deep appreciation to many who have contributed to this project: to the Agency for International Development for offering me the sponsorship and for its generous financial support during research implementation; to Dr. Kenneth Ebert of ISSO and Ms. Jane Tolbert and staff of the USAID office in Dar es salaam for sponsorship administrative support; to General Manager E. M. Makota and Directors B. A. Unga, Z. J. Mpogolo, and A. H. Mwenkalley of the Cashewnut Authority of Tanzania who made my data collection possible and a more rewarding experience; to my Guidance Committee: Professors R. H. Wilkinson, G. Brown, J. Gerrish, S. Yelon, M. Esmay, and R. Black who provided me with a day-to-day guidance and for their invaluable corrections, suggestions, and criticisms in the

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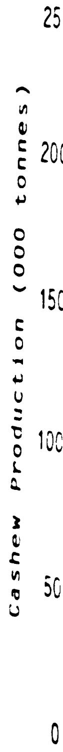
CHAPTER 1

INTRODUCTION

1.1. Purpose of Study

Estimates of the Food and Agriculture Organization (FAO) of the United Nations (1980) rank Tanzania fourth after India, Mozambique, and Brazil in terms of volume of cashewnut export trade. The world market price for the whole cashewnut kernel has been remarkably buoyant, with prices tending to remain firm even with increases in production (Menninger, 1977). The general trend, however, of the aggregate world cashewnut production is on the decline in all producer countries except Brazil (Figures 1.1-1.3). Reasons for the decline include droughts, poor transport and storage facilities, and, in the case of Tanzania, the destabilizing effects of the "villagization program" under which most individual producers were relocated to distances great enough that they could not effectively attend to their cashewnut plantations (Daily News, 1982).

Cashewnut production in Tanzania is predominantly a smallholder enterprise. Effective the 1984-85 season, the Cashewnut Authority of Tanzania (CATA)—which until the 1983-84 season was responsible for promoting cashewnut production, collection, processing, and marketing—will only


Cashew Production (000 tonnes)
25
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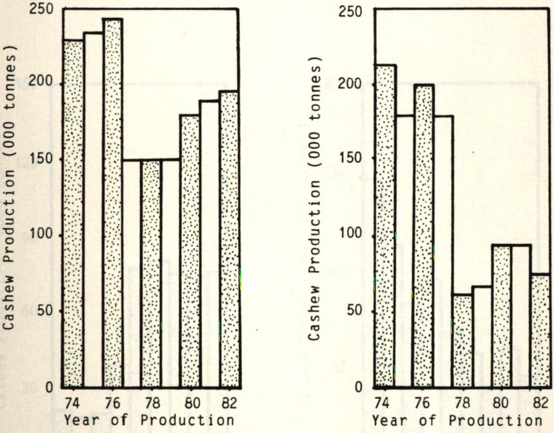
150
100
50
0

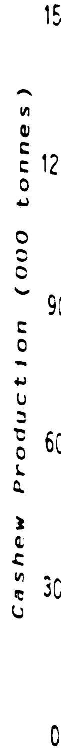


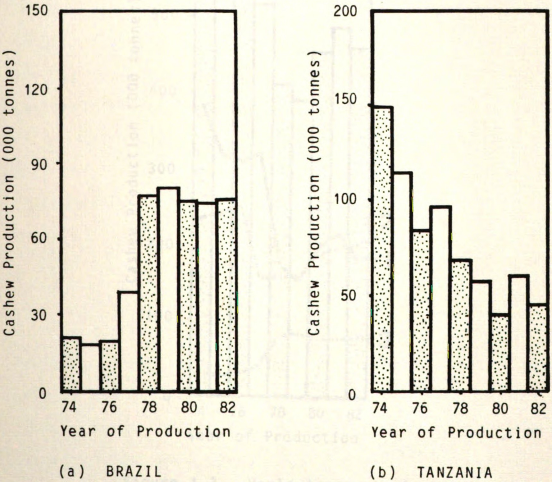
(a) INDIA

(b) MOZAMBIQUE

Figure 1.1. Cashewnut Production: India and Mozambique.

Source: FAO Production Yearbooks, Vols. 33, 34, 36.


15
12
9
6
3
0
Cashew Production (000 tonnes)



(a) BRAZIL

(b) TANZANIA

Figure 1.2. Cashewnut Production: Brazil and Tanzania.

Source: FAO Production Yearbooks, Vols. 33, 34, 36.

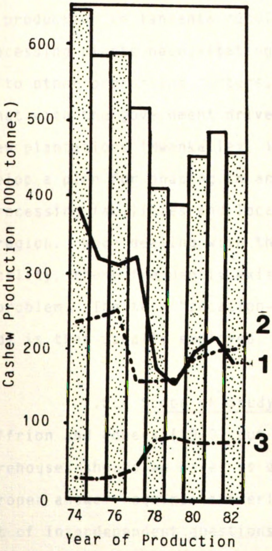


Figure 1.3. World Aggregate Cashew Production and Regional Trends: (1) Africa, (2) Asia, (3) South America.

Source: FAO Production Yearbooks, Vols. 33, 34, 36.

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act as a marketing-processing board (Makota, 1983). CATA currently operates thirteen processing plants scattered all over the cashewnut-producing region (Figure 1.4). The decline in production in Tanzania resulted in closure of several processing plants necessitating transshipment of raw cashews to other processing centers. It is anticipated, however, that with the government drive to encourage development of new plantations (Mwenkalley, 1983), there is a need to develop a plan for phasing in and phasing out cashewnut processing facilities and locating facilities within the region. When dealing with the location of more than one facility, there frequently exists an associated allocation problem. The term "location-allocation" as used in this study is then usually employed.

1.2. Scope of Study

As Geoffrion and Powers (1980) put it, "the question: How many warehouses should we have? is deceptively simple because a proper answer requires answering, at the same time, a host of interdependent questions." A comprehensive planning model with optimization capability should be a managerial tool that can be used to deal not only with facility location but also with a variety of additional management questions. So often the preoccupation with just locating facilities tends to distract from the wider range of issues that needs to be considered.

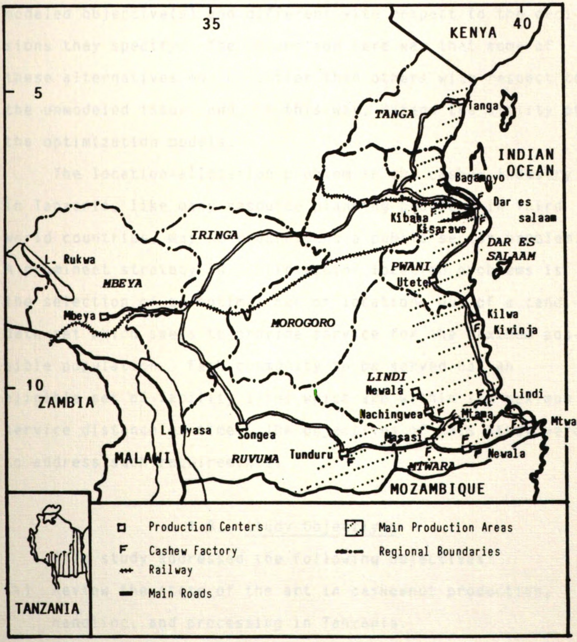

Figure 1.4. Tanzania Cashewnut Producing Regions.

It was therefore believed in this study that optimization models may be more effective and more useful to decision makers if these models were also used to generate planning alternatives that are good with respect to the modeled objective(s) and different with respect to the decisions they specify. The assumption here was that some of these alternatives may be better than others with respect to the unmodeled issues and, in this way, extend the utility of the optimization models.

The location-allocation problem in the cashew industry in Tanzania, like many resource planning problems in Third World countries, may be regarded as a public sector problem. A prominent strategy in public sector location problems is the selection of an optimal set of locations out of a candidate set which seeks to provide service for the maximum possible population. Each community to be served has an eligible set of facility sites which are within its maximum service distance or time. The objectives of this study were to address such requirements.

1.3. Study Objectives

This study addressed the following objectives:

(1) Review the state of the art in cashewnut production, handling, and processing in Tanzania.

(2) Develop a location-allocation model for planning optimal (or near optimal) plant locations and relocations for the cashewnut industry in Tanzania.

(3) Generate planning alternatives and formulate evaluation and elaboration criteria.

(4) Demonstrate the model's capability in planning a facility location system by answering the adaptive "what if" questions focusing on:
  (a) changes in demand* (production center production level) structure;
  (b) facility capacity changes; and,
  (c) forcing facilities into solution.

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*All production level figures in the text specified as "tonnes" or "tons" refer to metric tons (equivalent to 1000 kg).

CHAPTER 2

LITERATURE REVIEW

2.1. Cashew Studies and Cashew Growing

2.1.1. Distribution and Ecology

The cashewnut (Anarcadium occidentale Linn.) is native to tropical Central and South America (mainly Brazil) and the West Indies, but cultivation has spread to other tropical countries, notably Tanzania, Mozambique, Kenya, and India. Although it may be found growing at elevations up to 1200 m (4000 ft), it is best suited to lower elevations. Cashews have become naturalized in regions with average annual rainfalls ranging from 3800 mm (150 in) to as low as 500 mm (20 in). In parts of southern Tanzania, where cashews are grown on a substantial commercial scale, the average annual rainfall is commonly 760-1016 mm (30-40 in).

Cashews are often grown in soils that are considered too poor or stony for most other crops, but the trees prefer loams or sandy loams to very sandy soils. Whatever the nature of the topsoil, free drainage and the absence of brackish conditions are considered to be essential (Argles, 1975). Given soils with suitable textures, the cashew trees appear to tolerate a fairly wide range of pH values.

Little appears to be known about the reactions of cashews to temperature apart from the fact that they are sensitive to frost (Morton, 1962) and to excessively hot, dry weather such as occurs in parts of northern India. Nor has any information been encountered on their response to variations in day length.

2.1.2. Propagation by Seed

The large part of the cashewnuts that figure in expanding world trade are harvested from wild, self-sown seedlings or from plantations in which the trees have been raised in situ from seeds planted at stake. The preference for planting seeds at stake instead of growing them in nurseries arises from difficulties experienced in transplanting young seedlings (Garner, et al., 1975).

Cashew seeds vary markedly in size and weight, but only the latter is closely correlated with the kernel content because the larger nuts commonly contain air pockets between the kernel and shell or between the cotyledons and their kernels are sometimes defective. A more useful criterion of seed quality is its specific gravity. Sorting out seed on the basis of specific gravity has been done by using a sugar solution. In trials in Tanzania, four sugar solutions were used to separate cashewnuts into four categories with specific gravities ranging from below 1.000 to about 1.075. The speed of germination, the percentage germination, and yields in the first three harvest years rose progressively with each rise in the specific gravity of the seeds. This led to the general advice that only seeds which sink in a solution composed of .068 kg (1½ lb) sugar to 4.5 l (1 gal) water should be used for planting. The work on seed selection reported above is related to nuts collected at one time when they are fully mature. Studies in India and Tanzania suggest, however, that neither the time when the mature nuts are collected nor their stage of maturity are likely to affect germination appreciably (Turner, 1956; Rao and Hassan, 1956; Rao, et al., 1957; Morton, 1960; Mutter and Bigger, 1961; Northwood, 1967).

Although there is no experimental evidence reported, it is in fact often recommended that sun drying of cashewnuts intended for seed, sometimes as long as 12 to 14 days, should be conducted. On the other hand, chilling (exposure to 4°C for 15 minutes) has accelerated the germination of cashew seeds. In India, seed treatment with growth promoter gibberellic acid improved seed germination. Nuts that had been stored for 8 to 10 months, then soaked in water for 24 to 48 hours before planting, gave slightly improved germination percentage, and germination was hastened by one to four days. The overnight soaking of all cashew seeds, whether fresh or stored, is a generally recommended practice in Mysore, India. On trials in Italy, however, it was found that the viability of the nuts altered very little for two years after picking, provided they were kept dry (Rao and

Hassan, 1957; Rao, et al., 1957; Ibanez, 1968; Shanmugavelu, 1970).

The planting of seed at stake is normally done as early as possible during the rainy season. The usual practice is to prepare planting pits (46x46x46 cm in size) a month or more before the date of planting. The pits are left open until about two weeks before planting, after which they are filled with topsoil to which farm yard manure or compost may be added. Burned earth and ashes may also be added. Artificial fertilizers are not normally applied, although the application of rock phosphate is sometimes advocated, particularly when transplanting seedlings.

Recommendations for spacing vary widely among regions, ranging from 6x6 m (20x20 ft) to 12x12 m (40x40 ft) and up to 15x15 (50x50 ft) for windy sites. Dagg and Tadey (1967) reported that rainfall, rather than soil fertility, should be the factor given greatest attention when deciding on the spacing to adopt. As a partial insurance against pest predation and failure of some seeds to germinate, it is common practice to plant two or three seeds at each pit, individual seeds per hill being about 23 cm (9 in) apart. Where seeds are planted at stake, it is preferable to place the seed with stalk end upwards but inclined at an angle (Figure 2.1). An incorrect way of planting is shown in Figure 2.2. Figure 2.3, on the other hand, shows the effect of depth of planting on the average germination (Albuquerque, et al.,

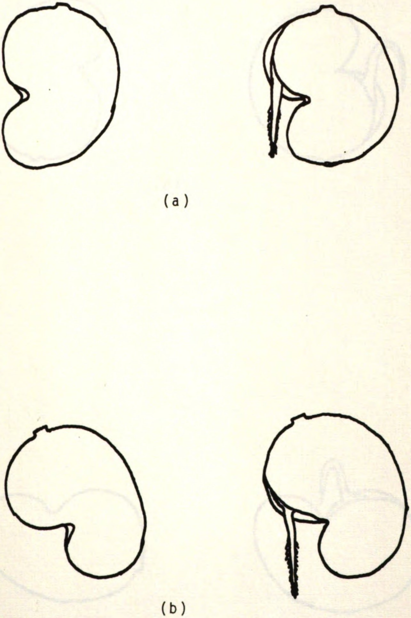


Figure 2.1. Correct Positioning: Seed Planted at Stake, Stalk-End Upwards.

(a) Straight
(b) Inclined

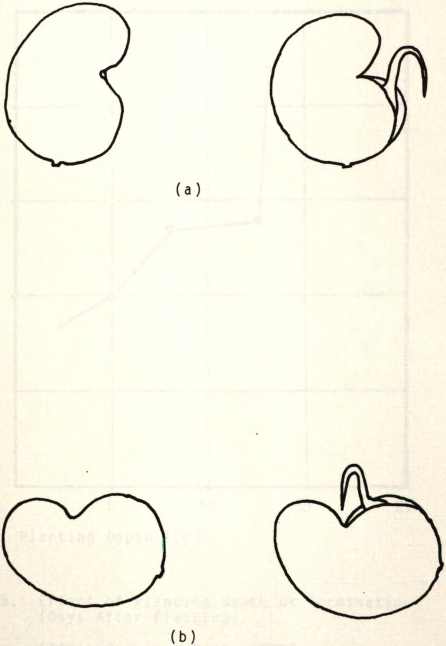


Figure 2.2. Incorrect Positioning: Seed Placement at Stake.

(a) Stalk-end down
(b) Stalk-end sidewards

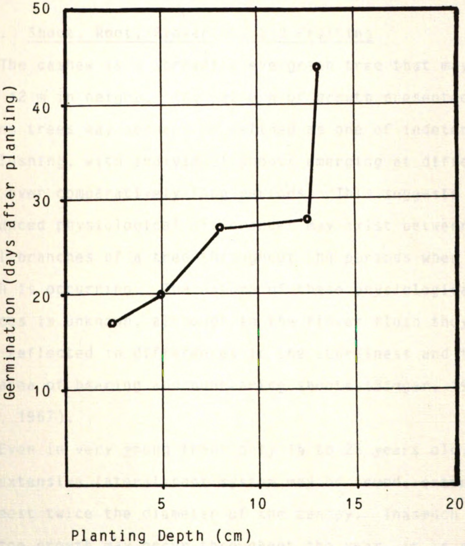


Figure 2.3. Effect of Planting Depth on Germination (Days After Planting).

(After Garner, et al. 1975)

1958; Ahmed, 1959; Saville and Bennison, 1959; Mutter and Bigger, 1961; Viswanathan, 1961; Garner, et al., 1975).

2.1.3. Shoot, Root, Flowering, and Fruiting

The cashew is a spreading evergreen tree that may reach 12 m in height. The pattern of growth presented by bearing trees may perhaps be defined as one of indeterminate flushing, with individual shoots emerging at different times over comparatively long periods. This suggests that pronounced physiological differences may exist between individual branches of a tree throughout the periods when the growth is occurring. The nature of these physiological differences is unknown, although in the flower flush they seem to be reflected in differences in the sturdiness and total leaf area of bearing and nonbearing shoots (Bigger, 1960; Ohler, 1967).

Even in very young trees only 1½ to 2½ years old, a very extensive lateral root system may be found, extending to almost twice the diameter of the canopy. Inasmuch as some top growth may occur throughout the year, it is probably safe to assume that some root growth is also taking place during the greater part of the year (Tsakiris and Northwood, 1967). Cashew trees usually start bearing appreciable crops in their third to fifth year, although some fruits may be borne on trees that are younger and sometimes little more than one year old (Ekrement, 1965; Northwood, 1966). Table 2.1 shows the estimates of yield from a cashew tree by age (CATA estimates).

The cashew inflorescence is a lax, terminal, many-flowered panicle in which male flowers outnumber hermaphrodite flowers, usually about six to one. Inflorescences are usually borne on only one of the main growth flushes, although, occasionally, some flowers and fruits are borne on one of the other growth flushes. In India, wind is thought to be the main pollinating agent, but elsewhere (East Africa and Brazil), various insects appear to play an important role. Following pollination, there may be a substantial fall of fruitlets, which is generally attributed to physiological causes but may also be accentuated by insect attack.

A period of two to three months elapses between fruit set and fruit maturity. The true fruit, or nut, reaches its maximum size during the first half of this period, whereas the fleshy cashew apple, consisting of an enlarged pedicel, receptacle, and disc, makes most of its growth during the second half of the period. The harvesting period lasts from 1½ to 3-4 months, depending on the region. In Tanzania, the harvesting period starts in October and extends to February.

Although light showers of rain during flowering may not be harmful and may even sometimes be beneficial, heavy rain during this period or during fruit development may result in crop loss. Cashews are also subject to attack in many areas

Table 2.1. Estimates of Cashew Nut Yields from a Cashew Tree (kg per tree per season versus age of tree).

Age of Tree (Years)	Yield of Raw Nuts per Tree (kg)	Yield of Raw Nuts per Hectare* (kg)
1	-	-
2	-	-
3	-	-
4	0.5	35
5	2.5	175
6	4.0	280
7	5.5	285
8	6.5	455
9	7.5	525
10	8.5	595
11	9.5	665

*1 hectare is equivalent to 70 trees at 10x12 m spacing.

by various species of thrips and by cuspid bugs (Helopeltis spp) as well as by fungal mildew (Bigger, 1960; Ohler, 1967).

2.2. Cashew Harvesting, Handling, and Processing

2.2.1. Cashew Harvesting, Handling, and Cashew Products

Ripe cashew fruits are not plucked from trees but are left to fall to the ground and collected by hand. The fruit (Figure 2.4) varies in size from 5 to 10 cm in length and 3.8 to 5 cm in width. It is yellowish-red in color and possesses a thin, waxy skin. It is broadly conical or pear-like in shape and is usually referred to as cashew "apple." The whole nuts are removed from the apples by hand with only a small percentage of "apples" spared for local consumption.

After the nuts have been gathered, they are sun dried for two to three days. During this time, the moisture content is reduced from 16% to 7% so that the nuts can be safely stored. The nuts are now either bagged and held for future processing or immediately processed.

The quality of cashew apple products (juicy, astringent, and nutritious, with a characteristic pleasant flavor rich in ascorbic acid, sugars, and vitamins) is largely influenced by the amount of astringency. Pantastico (1975) reports that there is a wide variation in the tannin content of juice extracted from fruits of different selections. Further, the major polyphenolic constituent in cashew apple juice has been found to be leuco-delphinidin. The juice can yield satisfactory blends with lime juice (1.5%) and pineapple juice (50%). This is then pasteurized in bottles or cans and, if stored at 26.7°C (80°F), may have a shelf life of about 32 weeks. The juice of the cashew apple may also be fermented and made into wine. Cashew apple wine distilled into a spirit or liqueur is highly potent. The fruit and wine, rich in vitamin C, possess antiscorbutic properties. Years ago, the liqueur was valued for its diuretic properties; it was believed to have a healthful effect on the kidneys and was prescribed in advanced cases of cholera. Other studies on biochemical and storage aspects of the cashew apple are reported by other authors; namely, Singh and Mathur (1953), Baile and Barcus (1970), Lopes (1972), and Maia, et al. (1975). Table 2.2 shows a typical composition of cashew apple.

Figure 2.5 shows a section of a cashew nut. The shell of the nut is hard, about 2.8 cm thick, and is of a honeycomb like structure on the inside. It consists of two layers with an oily liquid between them. The outer layer, which is smooth surfaced, is thin and hard. The inner layer is hard. Between the two layers is the difficult-to-handle cashew liquid (called cashewnut shell liquid, usually abbreviated as CNSL), which has a growing commercial importance.

The CNSL is comprised of aracardic acid, $C_{22}H_{32}O_{21}$, a brown crystalline substance, and cardol, $C_{21}H_{32}O_{21}$, a dark brown phenolic oil. Both are very toxic and irritating, producing blisters on the skin. CNSL has many industrial

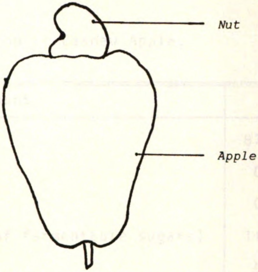


Figure 2.4. The Cashew Fruit: Nut and Apple.

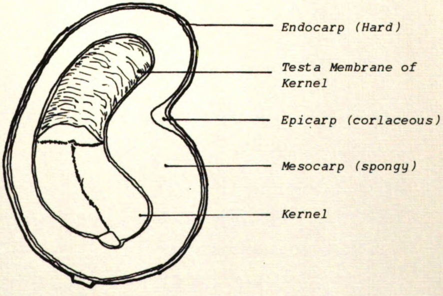


Figure 2.5. Section of a Cashew Nut.

Table 2.2. Composition of Cashew Apple.

Component	%
Moisture	87.8
Proteins	0.2
Fats	0.1
Carbohydrates (90% of fermentable sugars)	11.6
Calcium	0.01
Phosphorus	0.01
Iron	0.2 mg/100 g
Vitamin C	261.5 mg/100 g
Minerals	0.2

uses; it is used in making resins for the manufacture of varnishes, disinfectants, special inks, brake linings, and even lubricants. Several patents have been filed for the product (Menninger, 1977).

Cashews yield a number of commercial products, as summarized in Figure 2.6. These products are derivatives of the cashew apple and the nut. Table 2.3 shows the typical nutritive value of roasted cashew nuts (After Kuzio, 1977).

2.2.2. Nut Processing

Cashewnut processing procedures in East Africa are more mechanized than those in India and Brazil. The basic processing stages in all three regions, however, are the same. Figure 2.7 shows the steps involved in processing shelled nuts.

Six stages can be broadly categorized in terms of the functions to be accomplished. These include:

(a) Cleaning and First Calibration: This involves the removal of impurities from the outer shell. In Tanzania, this is accomplished by putting the nuts in a large tank which has jets of water and rotating brushes. As the nuts come out, they are then classified into two size grades (large and small) providing the first calibration. In India and Brazil, most cleansing of nuts is done by hand.

(b) Cashewnut Shell Liquid Extraction and Nut Preparation: This stage serves two purposes—the removal of CNSL and

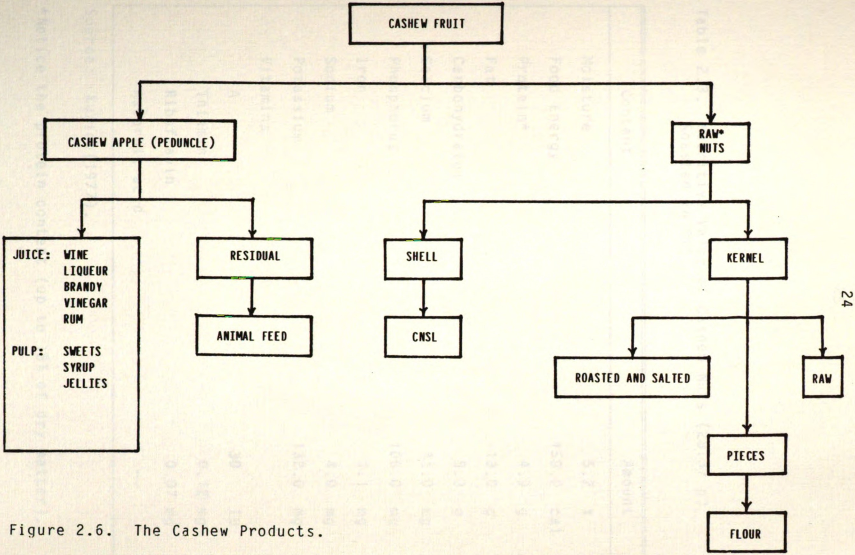


Figure 2.6. The Cashew Products.

*Refers to unroasted kernels. Only a small percentage of "apple" is utilized.

Table 2.3. Nutritive Value of Cashew Nuts (28.37 g) Roasted in Oil.

Content	Amount
Moisture	5.2 %
Food Energy	159.0 cal
Protein*	4.9 g
Fat	13.0 g
Carbohydrates	8.3 g
Calcium	11.0 mg
Phosphorus	106.0 mg
Iron	1.1 mg
Sodium	4.0 mg
Potassium	132.0 mg
Vitamins	
A	30 IU
Thiamin	0.12 mg
Riboflavin	0.07 mg
Ascorbic acid	—

Source: Kuzio (1977).

*Notice the protein content (up to 18% of dry matter).

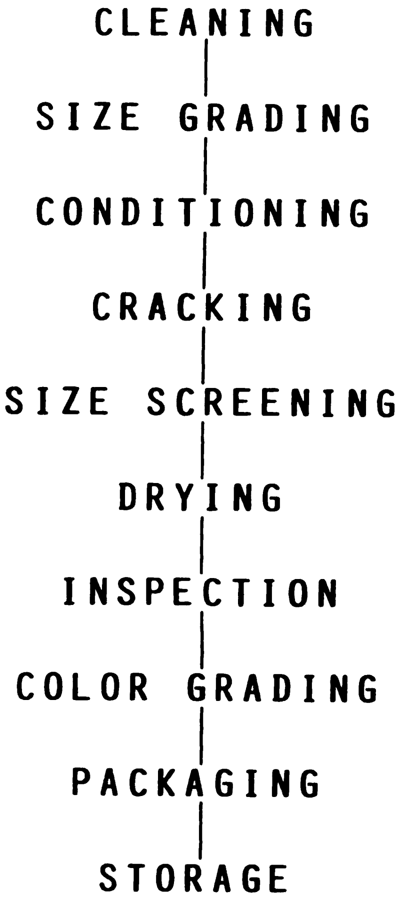


Figure 2.7. Twelve Steps in Processing Shelled Nuts.

contraction of the nut shell so that a space is created between the shell and the skin in order to facilitate shelling. In traditional processing units, the nuts are put into a metal drum and roasted over an open fire which is usually fed with spent shells. This traditional processing prevents any extraction of CNSL from the shell as most of it is burned off. In Tanzania, commercial factories employ another method of extraction called "CNSL Bath Extraction." In this method, nuts are put into a CNSL bath heated at about 195°-200°C for two hours. This creates explosive pressures within the nut and causes the "oil cells" of the pericarp to rupture, releasing CNSL into the bath for distilling. Another alternative involves putting the nuts in an autoclave which produces very hot steam under pressure and therefore producing the same effect as heating in a CNSL bath. This step extracts about 85% to 90% of the CNSL. The nuts are then allowed to cool for about 24 hours before shelling.

(c) Second Calibration and Shelling: The nuts are normally sorted into three size grades (small, medium, large) by using sieves (3/16", 5/16", and 5/8" sieve sizes) into separate bins. Manual shelling, which is only done in India, is accomplished by hand mostly by women workers seated on the floor using wooden sticks and carefully striking along the cleavage line of each nut, taking care not to break the kernel. As a protection, the workers dip their hands in vegetable oil in order to reduce the blistering effect of CNSL. They extract the kernel and put the shell in a basket of sawdust which will absorb extra CNSL. Using the hand-shelling method, an average of 14 kg per person can be cracked in an eight-hour day, and about 90% of the kernels are whole (Anon, 1966). In Brazil, pedal-powered shellers are used. About 80% of the kernels remain whole, and in an eight-hour day, about 25 kg are shelled per person. The drawback of the pedal-powered shelling method is the fact that broken kernels come into contact with CNSL and adhere to sheller blades and shells. Such contact discolors the kernels, affects the taste, and thus decreases the market value of the nuts. In Tanzania, this step is fully automated. In one kind of shelling machine used in Tanzania, the nut is mechanically directed into a gripper which moves against a circular saw. The blade cuts a groove into the shell; then a "scooping" device is inserted into the groove to remove the kernel in a manner similar to the "shucking" method used to open an oyster. Precision impact shellers are also used, where the nuts are spun at a certain angle and brought against a sharp position on the knife table for the shell to split. Once the nut has been split and separated, the products enter the shakers (in the case of the precision impact shellers) to separate kernels from shells or (in the case of circular saw type shellers) kernels drop through the screen into a picking belt to be examined for shells. The kernels then enter a flat platform belt for sorting and hence through the cylindrical grader, which classifies the kernels into different size grades. The circular saw type sheller (the most modern sheller) can crack up to 96 nuts per minute. Mechanical shellers have three serious drawbacks: (1) the machines can only produce about 60% whole kernels, (2) they are sophisticated pieces of equipment and susceptible to failures, and (3) they are expensive.

(d) Peeling: In manual systems, the kernels are dried after shelling and then placed between finger and thumb to rub off the skin (testa). Mechanical systems include steaming the kernels until the skin is very wet, then shooting steam jets to remove the skin by impact and friction. Usually steam jets tend to overheat and therefore scorching of kernels may occur resulting in yellow coloration of the kernels which places them in an undesirable classification. In Tanzania, the most preferred peeling method makes use of compressed air instead of steam (i.e., pneumatic peelers). After this step, the kernels are moved by conveyor belt across brushes to loosen and remove the remaining bits of skin which are picked up as the kernels pass through a slight vacuum induced at the end of the belt.

(e) Sorting and Classification: As yet, no machine can remove 100% of the skin. All systems must have some means, usually conveyor belts, whereby the kernels are checked manually for skin. Although optic selectors are in use in most factories in Tanzania, in most cases, manual sorting is also utilized. With optic selectors, the kernels are fed into the machine, and those kernels having dark spots or yellow coloration on passing through a beam of light will reflect relatively more light than spotless kernels. This triggers the sensor to induce an air jet which sorts out the colored kernels. Classification of cashew kernels is now standard throughout the world. Table 2.4 shows this classification. In mechanized systems, the sheller provides some preliminary classification.

(f) Packaging: Cashew kernels have historically been packed in 5-gallon tins holding approximately 11.3 kg of kernels. Currently, the tins are vacuum packed with carbon dioxide. The vacuum packers used in 10,000-ton capacity plants in Tanzania have a packing capacity of 400-450 tins per day. The use of aluminum-foiled polyethylene packages is being contemplated as an alternative to tins (Makota, 1983). Cashew kernels are normally sold raw, mainly to avoid the duties levied on finished products by the major importing countries.

Table 2.4. Cashew Kernel Classification: Grade Designations.

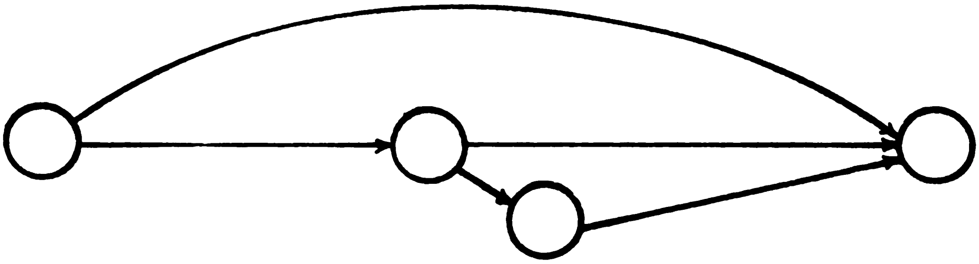
Grade	Descriptions	
	Kernels/lb	Kernels/kg
Whole		
W210	200-210	440-462
W240	220-240	484-528
W280	260-280	572-616
W320	300-320	660-704
W400	350-400	770-880
W450	400-450	881-990
W500	450-500	991-1100
Pieces		
DW I	Dessert White I	
DW II	Dessert White II	
LWP	Large White Pieces	
SWP	Small White Pieces	
DP	Dessert Pieces	
ScP	Scorched Pieces	

Source: Woodroof (1978) and CATA.

2.3. Distribution Planning Systems

The question of how many warehouses or plants should there be arises periodically at almost every company or institution offering or processing goods in the market place. This has led to numerous methods for determining facility location and has given rise to numerous computer programs addressing this problem for individual companies. The bulky and perishable nature of many agricultural products necessitates reviewing the degree of material handling to be employed, size of facility, and balancing advantages of nearness to customers against nearness to plants from a transportation viewpoint. In the instance of the cashewnut industry, issues of proper assignment of production centers to plants, proper use of cross-docking and plant direct supply, and proper pattern of inbound supply are important.

Distribution planning issues should, if possible, be dealt with simultaneously since they are interdependent. Ignoring some of the interactions or dealing with issues sequentially may yield misleading conclusions and result in poor decisions. It follows that a comprehensive distribution planning system along the lines of Figure 2.8 would be useful (Geoffrion and Powers, 1980). Such a model would enable calculation of performance measures (covering costs and agricultural product producers' service) for any consistent set of assumptions, collection of data, and design of the agricultural product handling system. Also incorporated



PRODUCTION CENTERS

- Minimum and maximum annual production level for each center
- Buying center costs (fixed and variable)

PROCESSING PLANTS

- Plant capacities
- Operating and fixed costs
- Commodities (products)
- Delivery policy

EXPORT OR CONSUMERS

- Customer demands for commodities
- Local and export markets

FREIGHT RATES: Inbound, Direct, Interwarehouse, Outbound

MAIN FUNCTION OF THE SOLVER:

Determine

- Number, location and size of plants
- Plant serving zones
- All transportation flows
- Source loadings

to minimize total cost

- Processing, transportation, warehousing
- Inventory and system reconfiguration

subject to appropriate constraints

- Processing capacity
- Producer service
- Single sourcing of plants

Figure 2.8. Sketch of a Comprehensive Distribution System: Agricultural Product Handling.

as part of Figure 2.8 is the function of the solver (solution algorithm) needed to find the best (cost minimization) design for the system for any consistent set of assumptions.

Geoffrion and Powers (1980) suggest that models of the type sketched in Figure 2.8 are most commonly run with non-optimizing algorithms (heuristics of one type or another). The reason is that true optimization has, until recently, been technically difficult to achieve due to the highly complex nature of the problems. Geoffrion and VanRoy (1979) discuss in depth the risks of using heuristics in distribution planning. The importance of solution comparisons necessitates solvers that have optimization capability as opposed to error-prone solutions of heuristic solvers.

A comprehensive distribution planning system along the lines of Figure 2.8 has a wide variety of potential uses. These uses may be grouped as follows:

(a) Network Rationalization Issues: These are designed to answer the basic question of what is the most appropriate structure for the agricultural product handling system and how should products flow through the structure to minimize total system operating costs given a certain required level of agricultural product producer service.

(b) Adaptive "What if . . .?" Issues: These allow model assumptions or data to be changed and reoptimization carried out in order to observe the change by comparison with "base case" or "reference" run. Several

"What if . . .?" situations from environmental changes (e.g., impact of changes in demand structure, impact of higher fuel and other energy costs, impact of strikes, natural disaster, weather closure, energy shortages) and business decisions and policies (e.g., production —plant capacity expansion proposals, plant location studies, impact of introducing new product line or discontinuing one; marketing—pricing policy analysis, split delivery policy analysis, expanding into new market; transportation—transportation policies, buying center capacity expansion or mechanization proposals, inventory policy comparisons; and others, including impact of combining autonomous institutional buying centers, evaluation of alternative distribution echelon structures, and implementation of priority analysis) may be incorporated.

(c) Parametric Studies: These involve systematic variation of single factors with optimization performed for several different values. The aim is to obtain a curve representing the essence of the influence of the factor being varied. These studies may help (Geoffrion, 1979) to quantify trade-offs between least system operating cost and agricultural product producers' service or the number of buying centers or plants. System sensitivity analysis with respect to any factor (e.g., inflation by cost category) as well as influence of demand change over time may also be investigated.

Indeed, a comprehensive optimizing distribution planning system has a surprisingly rich variety of uses beyond facility location, a must, particularly in public sector location analysis.

2.4. Optimization Techniques and Facility Location Analysis

2.4.1. Optimal Solution: An Aid to Analysts' Intuition

Optimization techniques have been used successfully to obtain "optimal" solutions to mathematical models. In conjunction with parametric or sensitivity analysis and a set of noninferior solutions using multiobjective methods, optimization techniques may also be used to derive a few "second best" solutions.

The last two decades have seen rapid advances in locational analysis. New methods of analysis, such as optimization techniques and mathematical models, are the roots of this expansion in capability. In spite of the vastly expanded spectrum of alternatives that one can use, the real world, with its immense complexity, tends to defy exact analogs. As Revelle, et al. (1970) observes, these methods of analysis are panacea for pouring out "optimal solutions." Indeed, models should be used as aids to provide insight into the sensitivity of solutions to changes in parameters, constraints, and criteria. Optimal results should be regarded as an aid to the analyst's intuition and not as a replacement for it.

Brill (1979), on the use of optimization models in public sector planning, concludes that both contemporary multiobjective programming formulations and the early least-cost optimization models were developed under the optimistic philosophy of obtaining "answers." But since most public sector planning problems are characterized by a multitude of local optima (which result from wavy indifference functions due to some of the important planning elements not being captured in the formulations), extensive parametric analysis is necessary to guarantee obtaining the best solution. In fact, omitted issues may imply that an optimal planning solution lies within the inferior region of a multiobjective analysis instead of along the noninferior frontier. Figures 2.9 and 2.10, adapted from Brill (1979) illustrate such limitations.

Differences inherent in using optimization models and in implementing solutions have been reported in many studies. Savas (1971), focusing on problems that are inherently political in nature, discusses the limitation of formal analysis techniques. Liebman (1976) observes that different members of society may not even be able to agree on a public goal, and, even when a common goal has been accepted, there is often disagreement over how the goal might be achieved. Liebman concludes that optimization methods "cannot and should not be used to resolve these

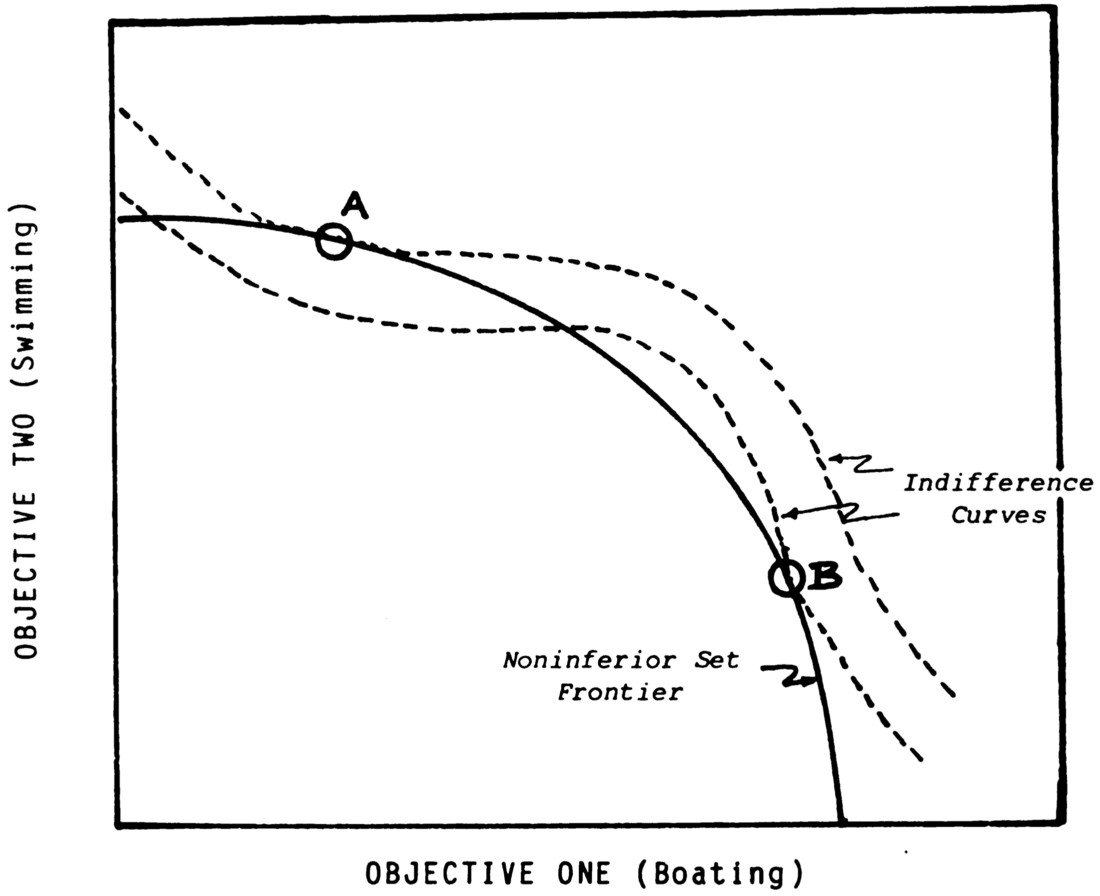


Figure 2.9. Planning Problem with Two Local Optima (Lakeside Park Problem).

A and B are local optima; A is global optimum.

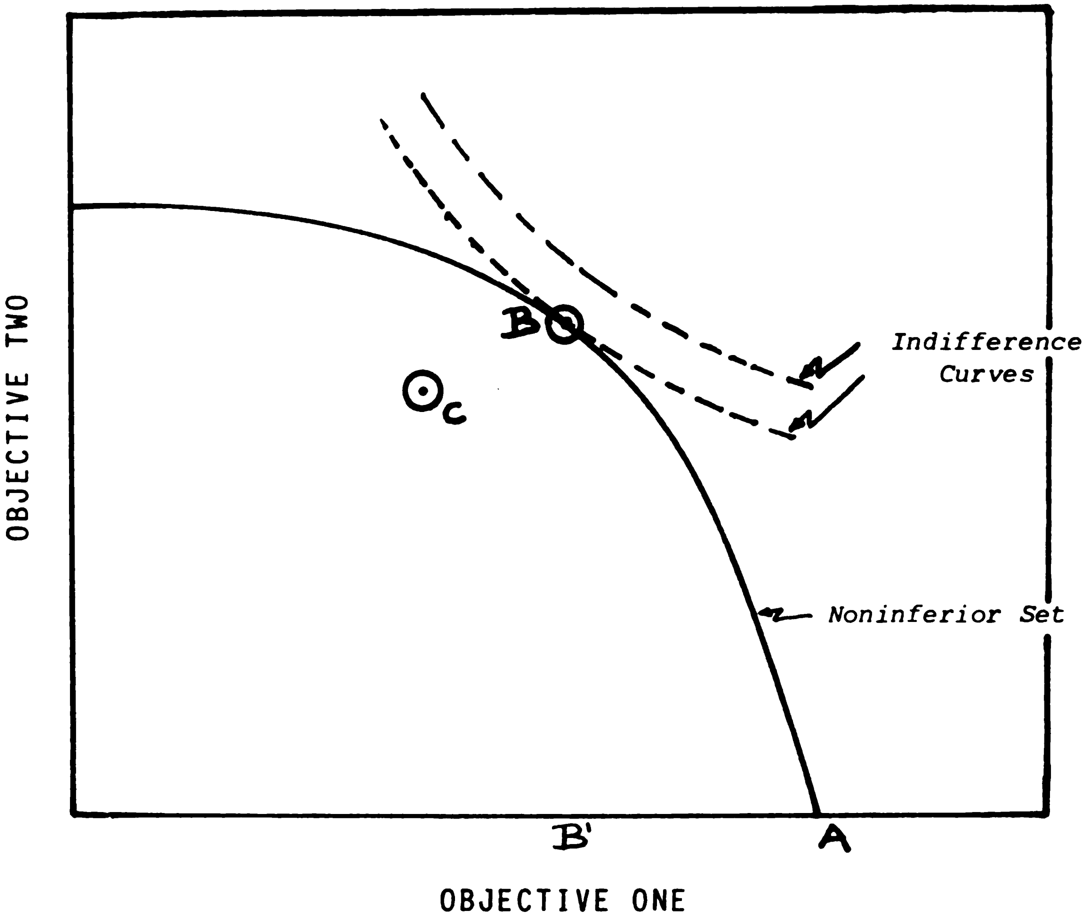


Figure 2.10. An Optimal Solution Within the Inferior Region of a Multiobjective Analysis: A Case for an Incomplete Multiobjective Model.

A = Best solution point if only Objective One is considered.
B = Best solution if Objectives One and Two are considered.
B' = Projection of B which lies in inferior region of Objective One.

conflicts" but should be used instead to provide "intuition, insight, and understanding which supplements that of the decision makers." Brill (1979) further suggests the joint use of models, analytical and optimization, and tailoring an available algorithm to provide information and insights. Brill, et al. (1982) illustrate such an approach (The Hop Skip Jump Method) in which a model is tailored to generate alternatives using a land use planning problem as an example.

2.4.2. Facility Location Problems: Scope

Due to philosophical and some other pragmatic differences, location problems may be divided into two sector location problems. Although both problems share the objective of maximization of some measure of utility while at the same time satisfying constraints on demands and other conditions, they differ in the way the objectives and constraints are formulated. Broadly speaking, however, they differ because of the ownership difference.

Revelle, et al. (1970) defines public sector models as those that are characterized by a criterion function involving a surrogate for social utility and constraint on investment in facilities or in the number of facilities. Private sector models, on the other hand, are distinguished as those in which the total cost of transport and facilities is isolated as the objective to be minimized. Although decisions on private sector location involve a host of issues, some of which are noneconomic in nature, minimization of cost or maximization of profit to the private owners is a reasonably accurate statement of the objective of the location decision. Public sector decisions, however, are made in response to a different set of owners—society as a whole —and, here, the objective is to minimize cost or maximize benefit, which is not easily quantifiable in monetary terms. As expected, a large portion of the analytical work for location analysis has been carried out on private sector problems.

Private sector location analysis poses the basic decision choice between the cost of investment and operation of facilities to meet the product demand and the cost of transportation. The trade-offs implied are centralization and decentralization of facilities. Revelle, et al. (1970) discusses additional factors that influence private sector location as including the stochastic nature of problems (such as variations in economic and weather conditions as well as seasonal variations that influence the demand of product) and time staging of construction, opening, expansion, relocation, or abandonment of facilities. Other factors include changes in competition, product acceptability and technology, and what has been referred to as "external effects," such as laws limiting environmental exploitation (i.e., pollution control, preservation of ecology).

Location decisions in public sector models involve all the private sector problems outlined above as well as having an additional dilemma that the goals, objectives, and constraints are neither easily quantifiable nor are they easily defined. The public sector problem may be thought to fall into two classes—ordinary services (e.g., post offices, schools, highways, water supplies, and waste disposal) and emergency services (e.g., hospitals, fire stations, and police).

There are two ways in which public sector problems may be handled. The first utilizes the objective function method normally used in private sector models where an attempt is made to identify and quantify factors affecting the social cost. This approach is difficult and has rarely been successful. The second analytical approach makes use of some surrogate for social utility. The attempt, here, is to try gaining some insight about the system under analysis rather than defining exact solutions. Examples of surrogates that can be used in public sector formulations as outlined by Revelle, et al. (1970) include:

(a) Average distance or time traveled to facilities by the user population. The smaller this quantity, the more accessible the system is to its users. The problem becomes one of minimizing total average distance traveled subject to a constraint on the number of facilities to be established.

(b) Creation of demand. Here, the user population is not considered fixed but is determined by the location, size, and number of central facilities. The greater the demand created, the more efficient the system is in fulfilling the needs of the region.

(c) Maximum distance or time between any facility in the set of the population area it is intended to serve.

These surrogates are then optimized subject to constraints on investment (in monetary terms or otherwise). It should be noted, here, that it is possible that the number of facilities may be set in the political arena and may not reflect budgetary restrictions. Once first solutions have been obtained, using such objectives and constraints outlined above, one can start to evaluate sensitivity of the solutions to parameter variations. If these parametric changes do not seriously influence the solution, then one examines the trade-offs between investment and utility. After considering other complexities which beset the analysis, such as user population characteristics and length of planning horizon, final choice might be made from among the alternatives generated at different levels of funding.

Savas (1978) discusses three measures of performance of public service; namely, efficiency, effectiveness, and equity. Efficiency measures the ratio of service outputs to service inputs (usually measured in monetary terms or in manpower). The service outputs are more difficult to define and measure adequately. Examples of service outputs may include the numbers of households serviced and throughput per year. These lead to efficiency measures such as cost per ton, cost per household per year, and tons collected per manhour. Among the ways of improving efficiency, research has focused on changes ranging from institutional arrangements for providing services (Savas, 1977) to changes in vehicle routing (Betrami and Bodin, 1973; Bodner, et al., 1970), man scheduling (Altman, et al., 1971; Ignall, et al., 1972), and siting of transfer stations or disposal points (Marks and Liebman, 1971) citing examples from refuse collection areas. For stationary service centers, a measure of travel time or travel distance for service recipients has been found adequate (Elshafei, 1975; Abernathy and Hershey, 1972).

Effectiveness measures the adequacy of service relative to need and incorporates the notion of service quality. It is difficult to measure effectiveness in public sector services; one of the ways used includes surveys of the level of citizen satisfaction. Equity refers to the fairness, impartiality, or equality of service. Equity is usually a concern of political scientists and economists. A number of different formulas, each equitable in a meaningful way, can be and are used to allocate or distribute public services. They can be subsumed under four general principles: equal payments, equal outputs, equal inputs, and equal satisfaction of demand (Savas, 1978).

2.4.3. Morphology of Location Systems

Location analysis problems may be classified into two major structural categories (Revelle, et al., 1970; Eilon, et al., 1971; Robers, 1971; Scott, 1971):

(1) Location on a Network: Characterized by a solution space consisting of points on the network (both nodes and points on the arc which joins the nodes) and distance measurement or time measurement (e.g., d_{ij} defined as the length or time of the shortest path from node i to node j) along the network.

(2) Location on a Plane: Characterized by an infinite solution space where facilities may be located anywhere on the plane and distance measured (d_{ij}) according to a specified metric. For example:

(a) Euclidean metric, such that:

$$d_{ij}^2 = (x_i - x_j)^2 + (y_i - y_j)^2 \qquad [2.1]$$

where d_{ij} is the distance between i and j and (x_i, y_i) are coordinates of the ith point in a rectangular system;

(b) Metropolitan metric, such that:

$$d_{ij} = |x_i - x_j| + |y_i - y_j| \qquad [2.2]$$

2.4.4. Location Analysis

The field of location theory is a large and topical one, as evidenced by the lengthy bibliographies of Francis and Goldstein (1974) and Lea (1973). Historically, location analysis began with Alfred Weber, who considered location on a plane of a factory between two sources and a single market. But it was the works of Kuhn and Kuenne (1962) and Cooper (1963) that stimulated interest in location analysis. Their works described an iterative procedure for solving the generalized Weber problem. The formulations were designed to find a single point which minimized the sum of the weighted Euclidean distances to that point. Thus, the objective was:

$$\text{Maximize } z = \Sigma_{i=1}^{n} w_i[(x_i-x_p)^2 + (y_i-y_p)^2]^{1/2} \qquad [2.3]$$

and thus:

$$d_{ip} = [(x_i-x_p)^2 + (y_i-y_p)^2]^{1/2} \qquad [2.4]$$

where:

d_{ip} = the Euclidean distance from point i to central point P

n = number of points which are served

w_i = the weight attached to the ith point (goods demanded, resources spent, population served, etc.)

x_i, x_p = the location of the ith point relative to some fixed cartesian coordinate system

x_p, y_p = the unknown coordinate of the central point P

Partial differentiation with respect to x_p and y_p yields a pair of equations, below, which have no direct solution to these variables:

$$\frac{\partial z}{\partial x_p} = \Sigma_i \frac{w_i(x_i - x_p)}{d_{ip}} = 0 \qquad [2.5]$$

$$\frac{\partial z}{\partial y_p} = \Sigma_i \frac{w_i(y_i - y_p)}{d_{ip}} = 0 \qquad [2.6]$$

The iterative procedure suggested involves solving Equations 2.5 and 2.6 for x_p and y_p in terms of w_i, x_i, y_i, and d_{ip}, i.e.:

$$x_p = \Sigma_i \frac{w_i x_i}{d_{ip}} / \Sigma_i \frac{w_i}{d_{ip}} \qquad [2.7]$$

$$y_p = \Sigma_i \frac{w_i y_i}{d_{ip}} / \Sigma_i \frac{w_i}{d_{ip}} \qquad [2.8]$$

The value of d_{ip} is then recalculated using Equation 2.4 and the procedure repeated until successive differences between values of x_p and y_p are negligible.

Eucledian problems may find applications in both private and public sectors such as in warehouse locations where goods are distributed from central points and where

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demands emanate from outlying points to the central supply point, respectively. Problems of locating central points on a network have also received a lot of attention in both public and private sector analysis. The problem of plant or warehouse location has the following general characteristics: given a number of demand areas for a certain product, each with specified demand and a number of alternative sites where facilities may be built to satisfy these demands, determine where the facilities may be placed and which demand areas are to be served by a given facility. The general mathematical formulation of the warehouse or plant location problem applicable to the private sector is:

$$\text{Minimize } z = \Sigma_{j=1}^{n} \Sigma_{i=1}^{m} d_{ij}(x_{ij}) + \Sigma_{i=1}^{m} F_i(y_i) \qquad [2.9]$$

subject to:

$$\Sigma_{j=1}^{n} x_{ij} = y_i \qquad \forall_i \qquad [2.10]$$

$$\Sigma_{i=1}^{m} x_{ij} = D_j \qquad \forall_j \qquad [2.11]$$

$$x_{ij} \geq 0 \qquad \forall_{i,j} \qquad [2.12]$$

$$y_i \geq 0 \qquad \forall_i \qquad [2.13]$$

where:

D_j = the demand at area j

$d_{ij}(x_{ij})$ = cost of shipping quantity x_{ij} from i to j

$F_i(y_i)$ = cost of establishing and operating a facility at site i, where y_i is being shipped from i

m = number of proposed warehouse facility sites

n = number of demand areas

x_{ij} = amount shipped from facility i to demand area j

y_i = total amount shipped from facility i

The function $F_i(y_i)$ is, unfortunately, frequently nonlinear and generally exhibits a large fixed charge on investment. The function is therefore usually concave and not amenable to linear programming. The method of treating the concave cost function has been the key element of most procedures in past research. Haldi and Whitcomb (1967), on economies of scale in production, have conveniently assumed taking the form of a concave cost function which is approximated by a piecewise linear function. The differences between solution procedures are then influenced by the shape of the approximation adopted (Elshafei, 1975). Examples of such approximations are shown in Figures 2.11 to 2.13.

Sá (1969) and Ellwein and Gray (1971) adopted the approximation shown in Figure 2.11 and both developed branch and bound algorithms to solve the problem. Kuehn and Hamburger (1963), in their heuristic approach for locating warehouses, assumed an approximation that transport costs are linear in the amount shipped and that facility costs are of the following form:

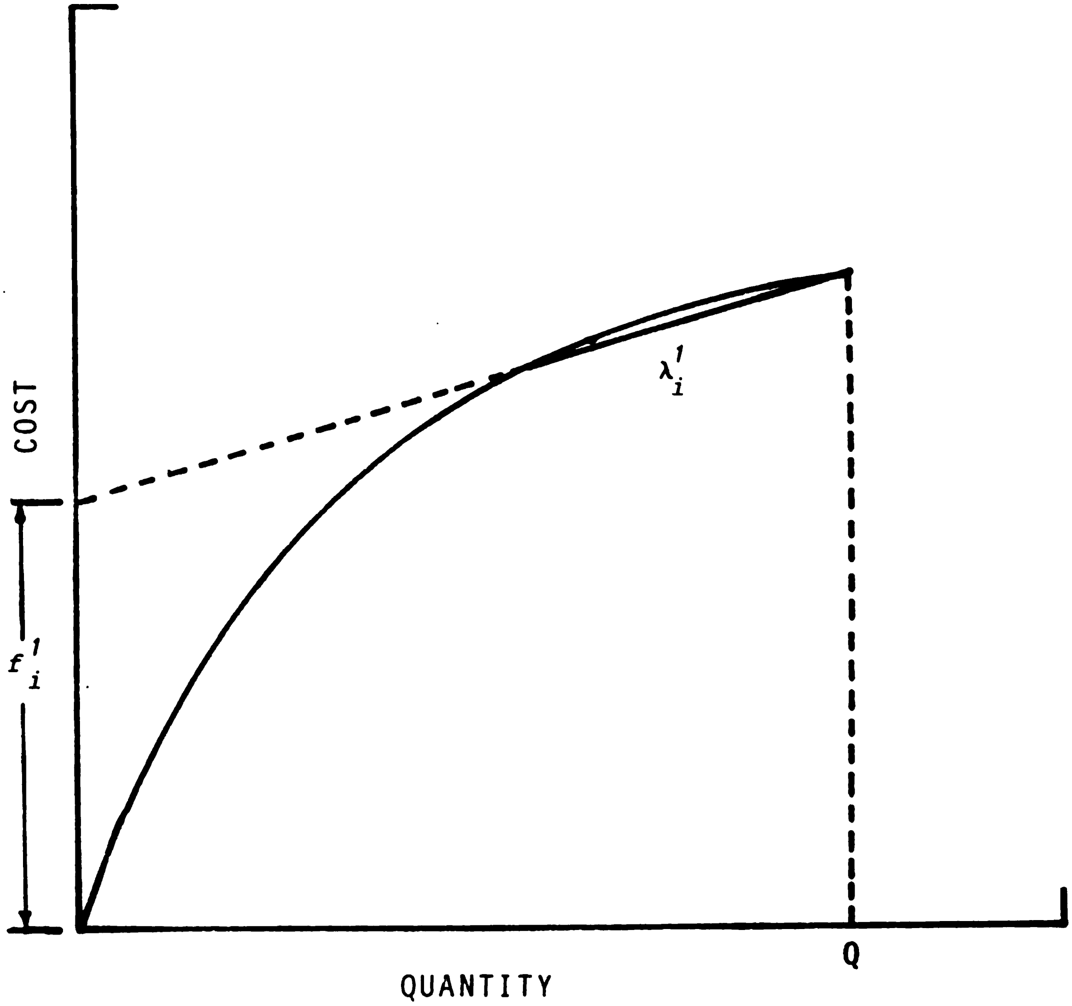
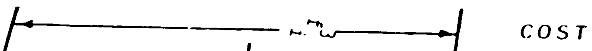


Figure 2.11. Fixed Charge Approximation for a Concave Cost Function X.

λ_i^1 = fixed charge for operating costs

f_i^1 = fixed cost



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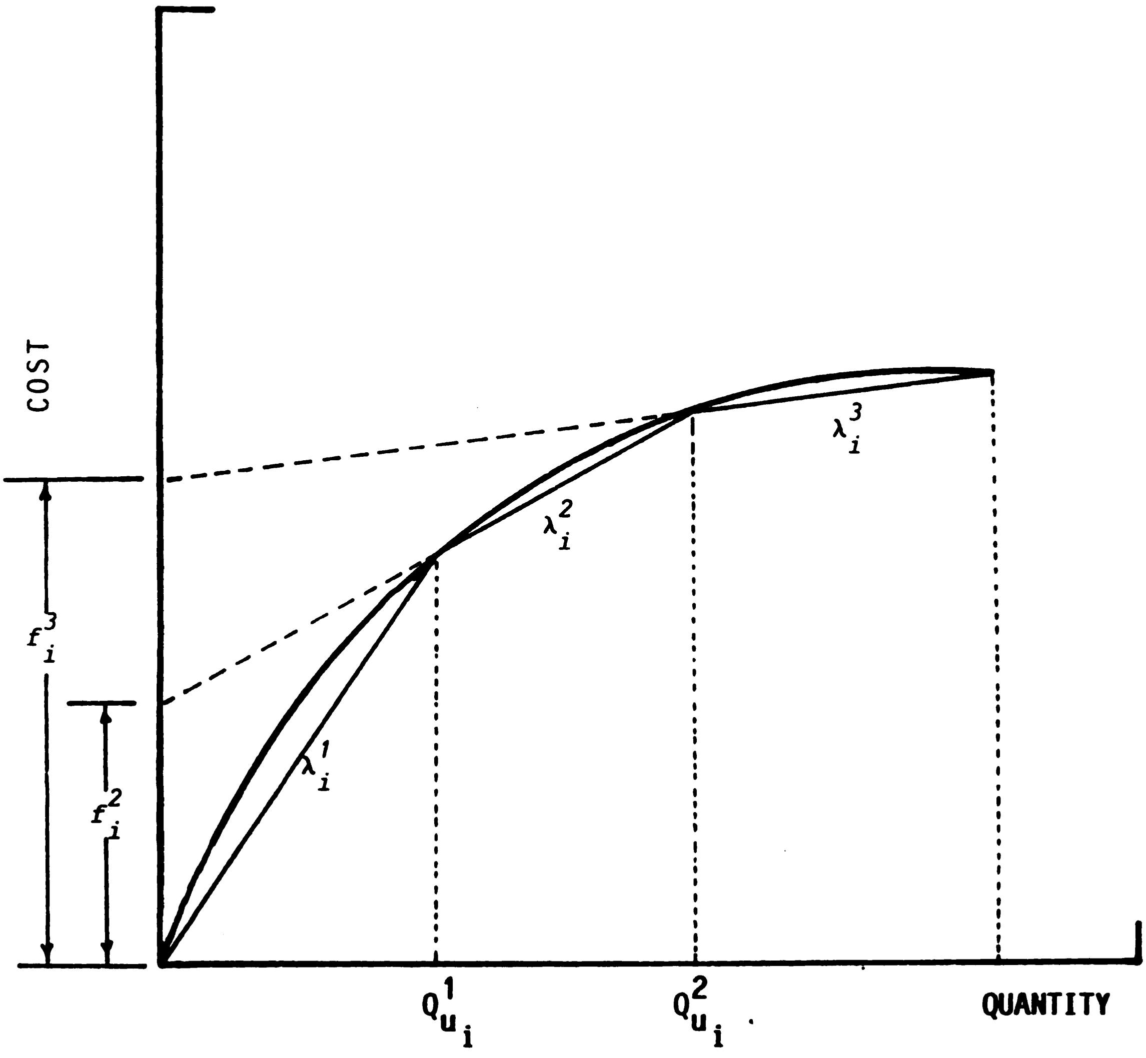

Figure 2.12. Two Piecewise Linear Fixed Variable Cost Approximations.

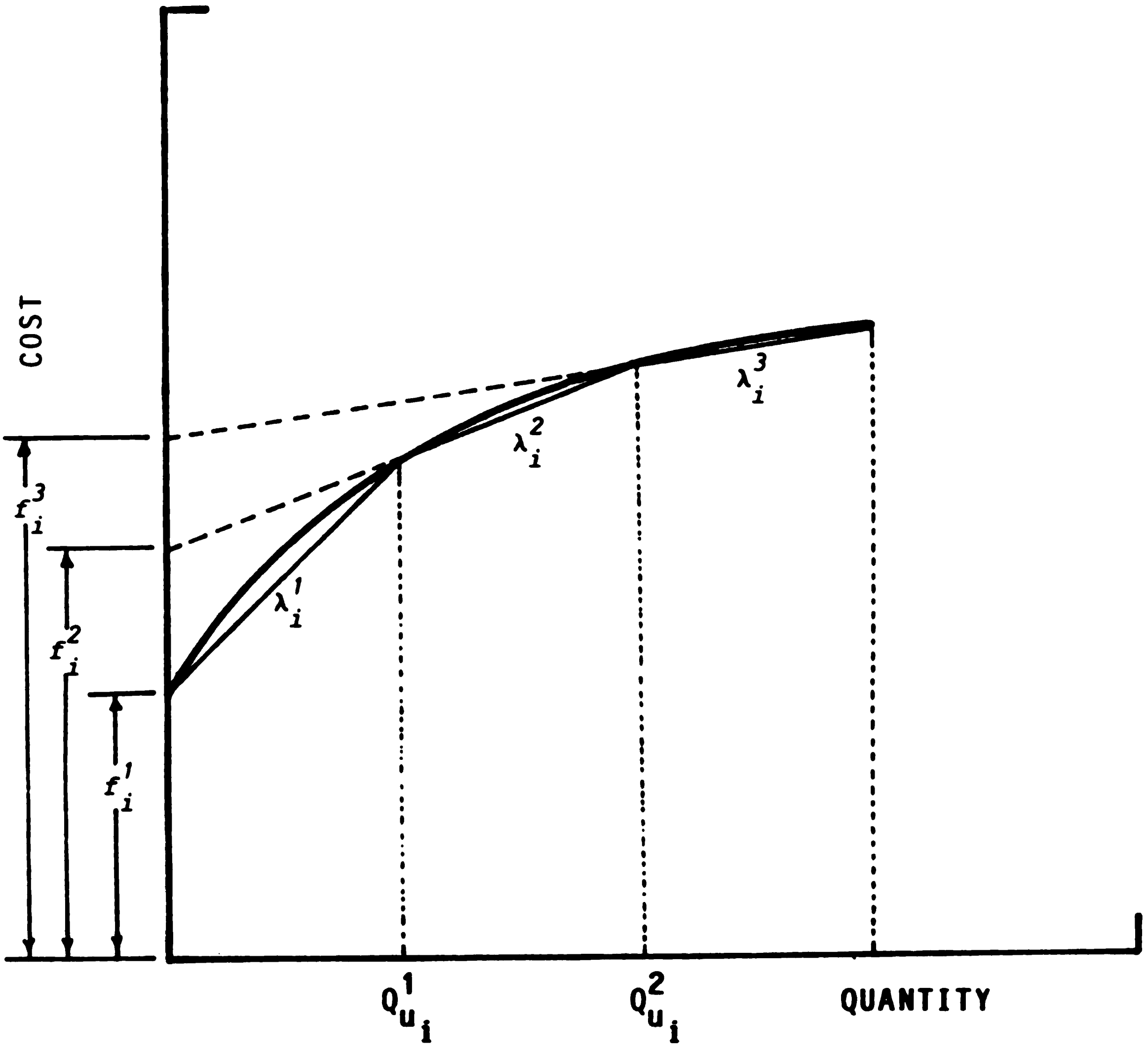

Figure 2.13. Three Linear Segments in the Piecewise Linear Approximation.

f_i = fixed annual charge at location

λ_i = facility i's variable cost per unit

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$$F_i(y_i) = a_i + b_i y_i \qquad \text{if facility exists} \qquad [2.14]$$

$$= 0 \qquad \text{otherwise} \qquad [2.15]$$

That is, $F_i(y_i)$ consists of a fixed charge (a_i), which is independent of the storage or production, and a linear cost, which depends on storage or production (in case of plants) if a facility exists. The expansion cost, b_i, is assumed constant for each facility. The solution algorithm begins with a single facility, and one additional facility is added every time until it appears that another facility cannot be added without increasing total cost. The assumption is that the best N facilities are contained in the set of the best N+1 facilities.

On the other hand, Feldman, et al. (1966) assumed a more general form for facility cost—that of a continuous concave cost function. They also assumed that the transportations costs were linear in the amount shipped between points. Since $F_i(y_i)$ did not have an expansion cost component in this case, the assignment of demand areas to existing facilities was much more difficult to accomplish. The authors resorted to an approximation method. Hence, the algorithm by Feldman, et al., started with all facilities and dropped out individual facilities one at a time. Solution was achieved when no further savings were realized by further facility elimination.

Two other approaches to incorporating economies of scale of facility systems have been the tangent line approximation reported by Khumawala (1974) and the chord approximation method used by Soland (1974). An obvious shortcoming of tangent line approximation is that using tangents only focuses on the variable costs so that fixed costs do not influence the ensuing facility assignments. Soland's approach overcomes this drawback by use of the chord (convex envelope) cost approximations. The drawback with the chord approximation approach, however, is that resulting lower bounds are generally weak and a very large solution tree must be generated (due to typically large numbers of nodes). A combined tangent-chord approximation of costs as shown in Figure 2.14 (Kelly and Khumawala, 1982) combines the advantages of the two approaches.

Efroymson and Ray (1966) presented a solution procedure to a related but more constrained problem than that of Feldman, et al. (1966) utilizing an implicit enumeration technique—the branch-and-bound algorithm. This selective enumeration (Figure 2.15) was guided at each stage by a bound on the value of the objective function obtained at that stage. Computational experience on problems with 50 possible facility locations and 200 demand areas up to 100 facilities and 150 demand areas have been reported by Efroymson and Ray and by Spielburg (1969), respectively. The branch-and-bound algorithm used by Spielburg had some added features to speed up computation.

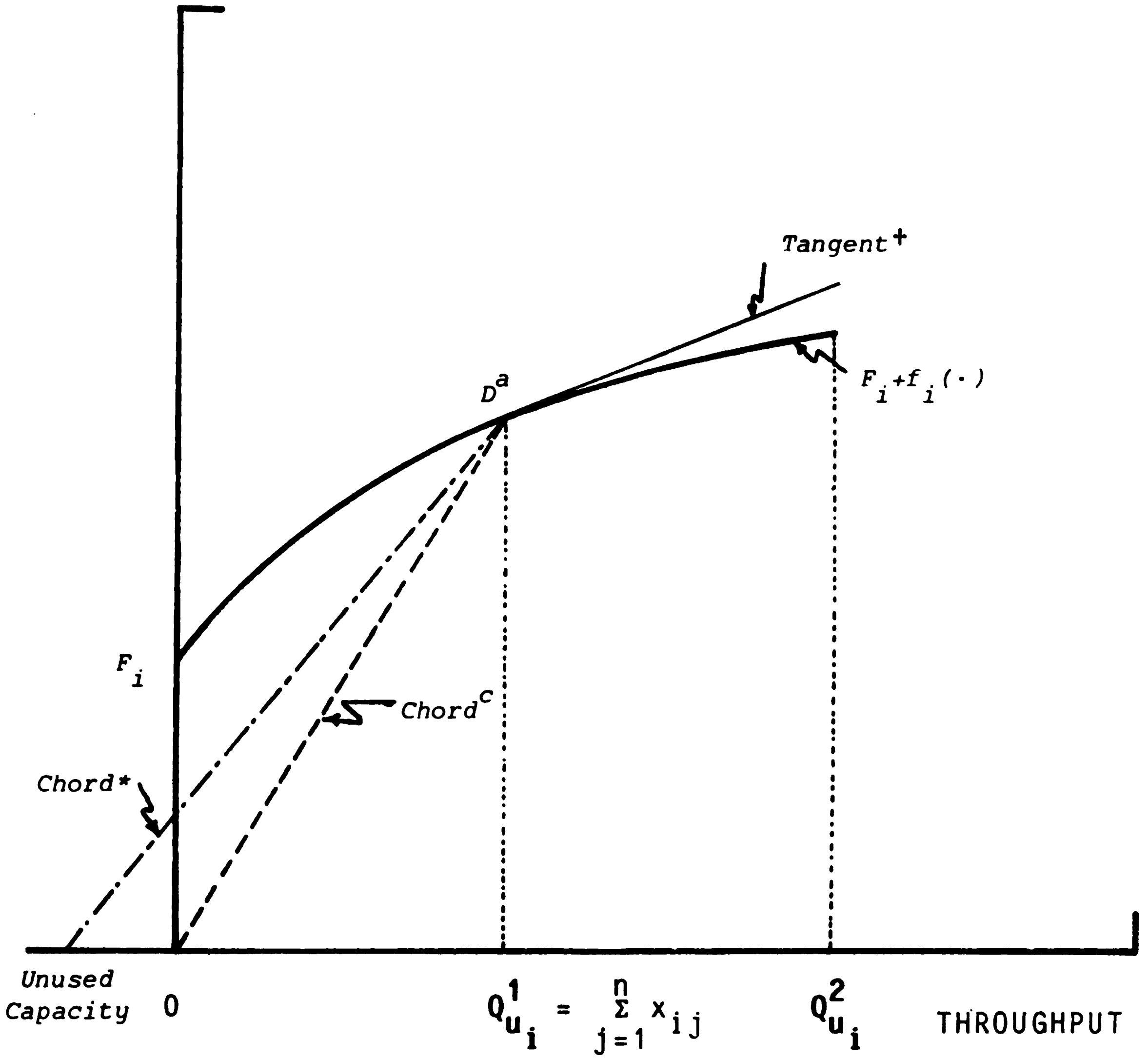


Figure 2.14. Tangent-Chord Approximation to Facility Costs for Potential Facility i.

+Marginal increases in facility throughput cause movement upward to the right along the tangent.

*Marginal decreases in facility throughput cause movement downward to the left along the chord.

[a] Chords pass through the origin when there is no unused facility capacity.

[c] Changes in throughput changes the cost reference point.

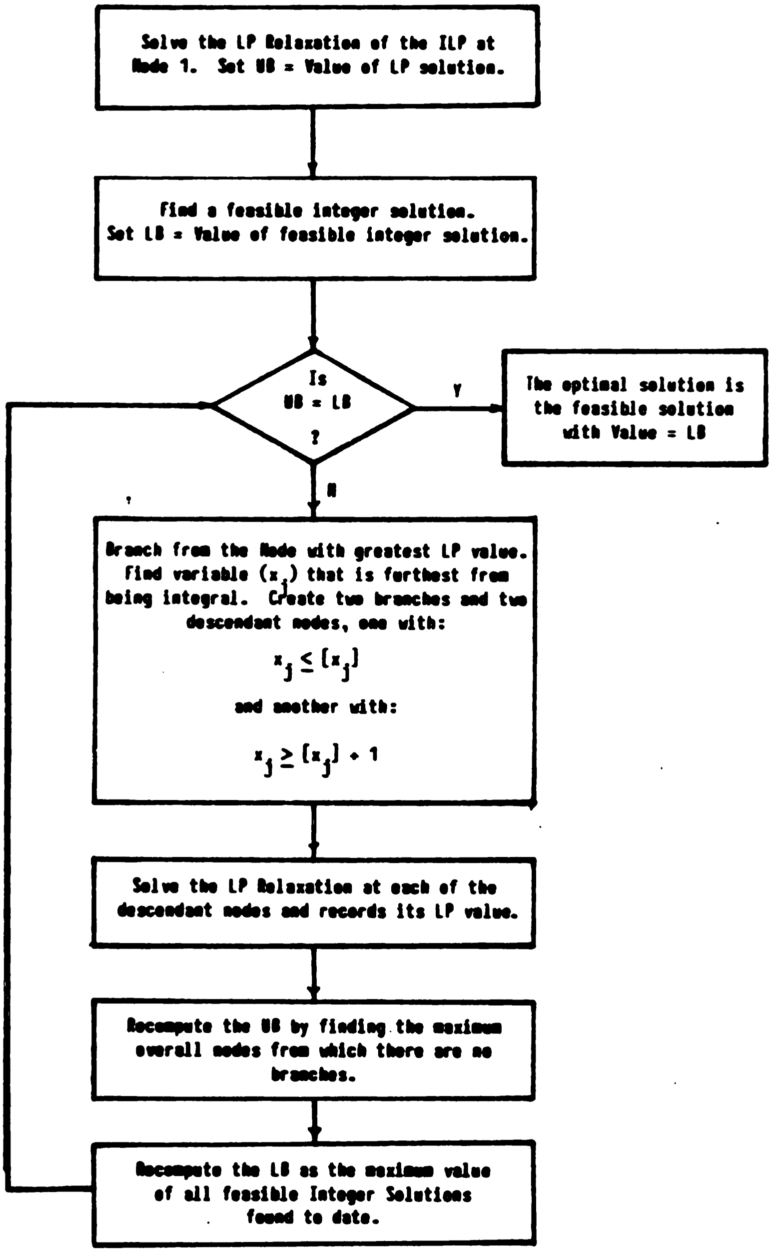


Figure 2.15. A General Branch-and-Bound Solution Procedure for All Integer Linear Programs (after Anderson, et al., 1982).

Revelle, et al. (1970), on work by Marks (1969), reported a formulation for a fixed charge, transshipment, facility location problem. The model allowed the facilities to be constrained in their capacity, and the warehouses were considered as intermediate points between sources of product and demand centers. If either the sources or the demand areas of product were dropped, the problem reduced to a general warehouse problem, as outlined previously. The problem was then to determine which facilities should be established and which supply and demand areas each facility should serve in order to minimize the total costs of facilities and transshipment. The mathematical formulation of the problem was:

$$\text{Minimize } \Sigma^{m}_{i=1} F_i y_i + \Sigma^{m}_{i=1} \Sigma^{n}_{j=1} C^{*}_{ij} X^{*}_{ij} + \Sigma^{m}_{i=1} \Sigma^{\rho}_{k=1} C^{**}_{ki} X^{**}_{ki} \quad [2.16]$$

subject to:

$$\Sigma^{m}_{i=1} X^{**}_{ki} \leq S_k \qquad \forall_k \qquad [2.17]$$

$$\Sigma^{n}_{j=1} S^{*}_{ij} = \Sigma^{\rho}_{k=1} X^{**}_{ki} \qquad \forall_i \qquad [2.18]$$

$$\Sigma^{\rho}_{k=1} X^{**}_{ki} \leq Q_i Y_i \qquad \forall_i \qquad [2.19]$$

$$D^{u}_{j} \geq \Sigma^{m}_{i=1} X^{*}_{ij} \geq D^{l}_{j} \qquad \forall_j \qquad [2.20]$$

$$X^{*}_{ij}, X^{**}_{ki} \geq 0 \text{ and } Y_i = (0, 1) \qquad [2.21]$$

where:

C^{**}_{ij} = $C_{ij}+R_j$ = unit cost associated with a transfer of material from facility i to sink j

C_{ij} = unit shipping cost from facility i to sink j

R_j = unit variable cost associated with sink j

Y_i = 1, if the ith facility is built; = 0 otherwise

X^*_{ij} = flow of material from facility i to sink j

X^{**}_{ki} = flow of material from source k to intermediate point i

C^{**}_{ki} = $C'_{ki}+T_k+V_i$ = unit cost associated with the transfer of material from source k to facility i

C'_{ki} = unit shipping cost from source k to facility i

T_k = unit variable cost associated with using source k

V_i = unit variable cost associated with using facility i

F_i = fixed charge for establishing facility i

S_k = amount supplied at source k

D^u_j = upper bound on amount demanded at sink j

D^l_j = lower bound on amount demanded at sink j

Q_i = capacity of the ith facility

m = number of proposed facility sites

n = number of demand areas

ρ = number of supply points

The solution technique was based on a network algorithm. Figures 2.16 and 2.17 show the network representation and the fixed charge cost function and its approximation, respectively. A capacitated node for each facility was

m = 2
n = 3
k = 2

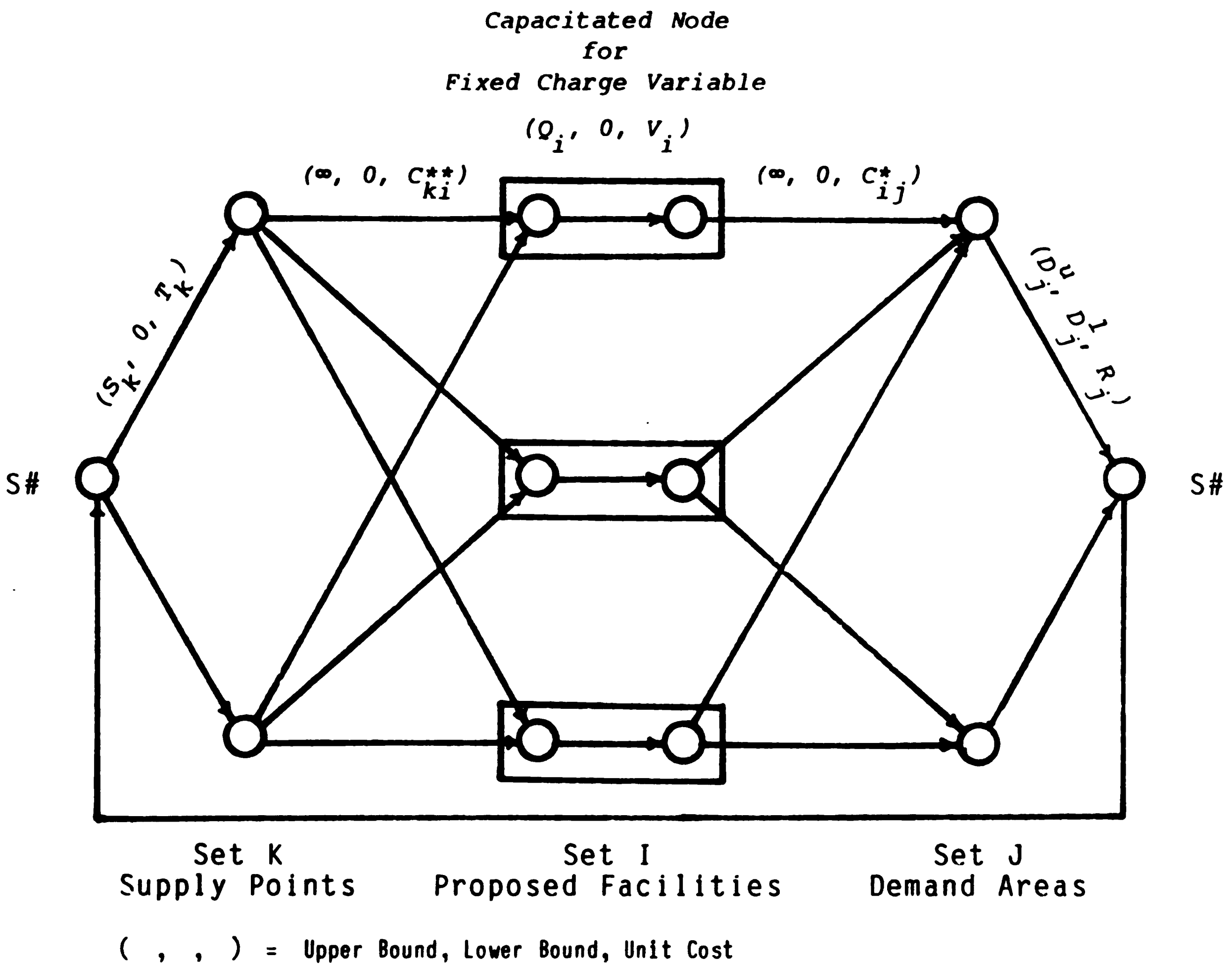


Figure 2.16. Graphical Representation of the Problem.

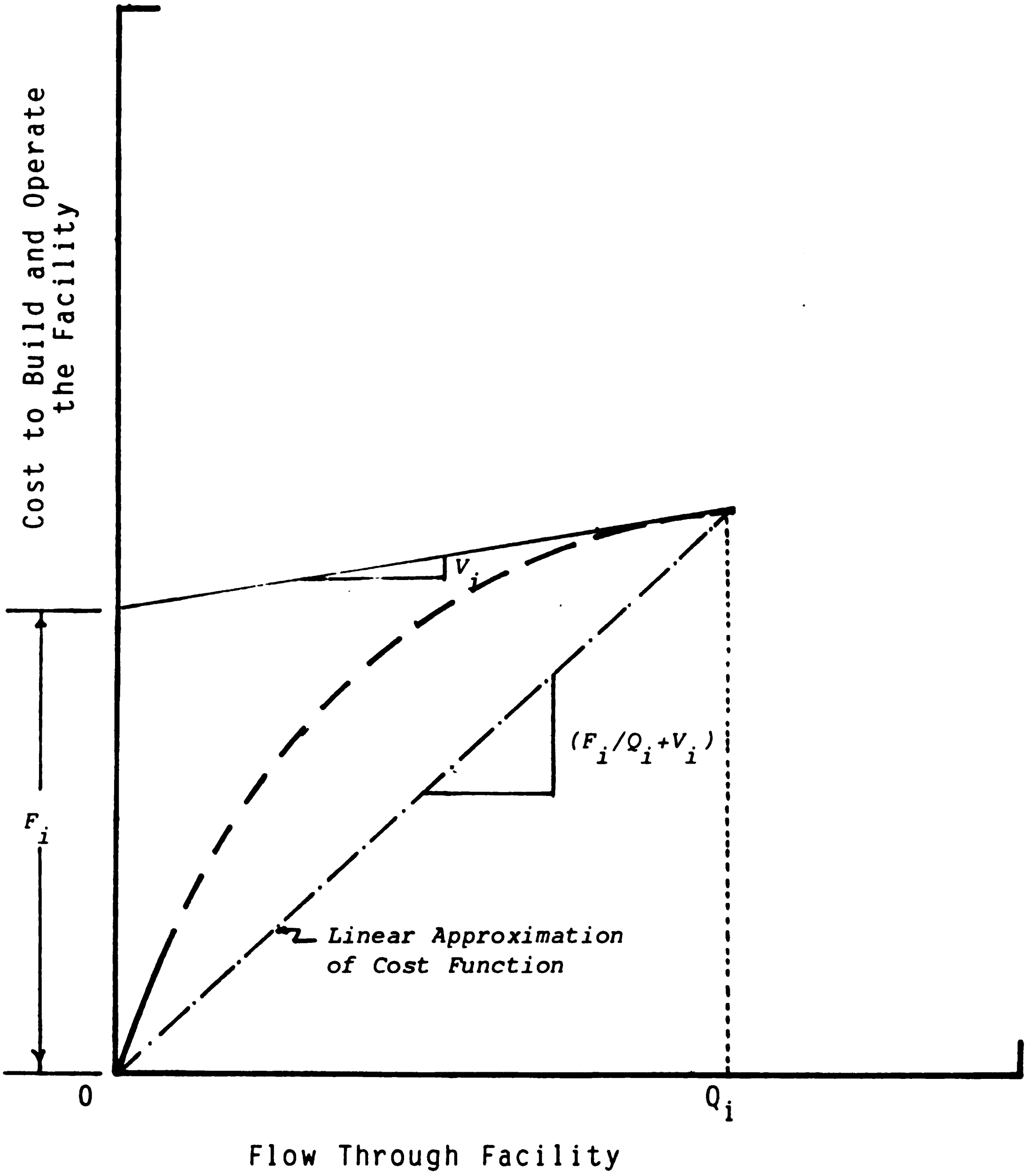


Figure 2.17. The Fixed Charge Cost Function and Its Approximation.

added so that capacity constraints and a linear cost function could be defined for each facility location. It should be noted that the approximate cost function underestimated the true cost function except when the flow through the facility was zero or equal to Q_i, the capacity of the facility. It was this approximation that formed the basis for the branch-and-bound solution scheme. Assuming that all facilities were open and had an approximate cost function, the initial problem was solved using an out-of-kilter algorithm. The optimal solution to the fixed charge problem was found if the resulting solution was such that the flow through each facility was zero or the capacity of the facility. If not, branching took place, and a facility with its fixed charge was included or excluded from the solution until optimal solution was realized and verified.

Hakimi (1964, 1965) proved for the case of a specified number of facilities that there was an optimal solution to such problems which consisted of all facilities located at nodes. Levy (1967) extended these by reporting his theorems to cases of concave transportation and facility establishment costs. Maranzana (1964) utilized an heuristic method to locate a specified number of warehouses to serve a region of specified demands. The solution criterion was a minimization of transportation costs. Although the work was directed toward the private sector problem, it fit, however, in public sector models, since the criterion was isolated and distinct from the constraint on the number of facilities which normally characterized the private sector location problems.

A number of facility location and location-allocation problems can be formulated and solved as generalized assignment problems (GAPs). The GAP is a 0-1 programming model in which it is desired to minimize the cost of assigning n "tasks" to a subset of m "agents." Each task must be assigned to one agent, but each agent is limited only by the amount of resource, e.g., available time (Ross and Soland, 1977). Ross and Soland (1975) outlined an efficient algorithm (branch-and-bound) for GAPs. A mathematical formulation of the GAP is:

$$\text{Minimize} \quad \sum_{i \varepsilon I} \sum_{j \varepsilon J} C_{ij} X_{ij} \qquad [2.22]$$

subject to:

$$A_i \leq \sum_{j \varepsilon J} r_{ij} X_{ij} \leq b_i \qquad \forall_i \qquad [2.23]$$

$$\sum_{i \varepsilon I} X_{ij} = 1 \qquad \forall_j \qquad [2.24]$$

$$X_{ij} = 0 \text{ or } 1 \qquad \forall_{i,j} \qquad [2.25]$$

where:

$I \equiv (1,2,...,m)$ is a set of agent indices

$J \equiv (1,2,...,n)$ is a set of task indices

C_{ij} = cost incurred if task j is assigned agent i

$r_{ij} > 0$ is amount of resource required by agent i to perform task j

$A_i \geq 0$ and $b_i > 0$ are the minimum and maximum amounts of the resources that may be expected by agent i

X_{ij} = 1 or 0 decision variable if task j is assigned to agent i or otherwise

In facility location problems, the "task" generally represents centers of demand for a good or service and the "agents" represent the supply centers which supplies the goods or services. However, it should be noted, here, that goods or services may actually move from the supply centers to demand centers (Toregas, et al., 1971; Geoffrion and Graves, 1974) or vice versa (Maier and Vander Weide, 1974). The objective function should therefore provide the appropriate measure of total cost of the supply system. Figure 2.18 shows a convenient way of utilizing a tableau representation of the data and special features of a GAP (Ross and Soland, 1977). Figure 2.19 and Figure 2.20 give summaries in tableau form of a ρ-median problem and a median problem with capacity and investment constraints, respectively.

When capacity restrictions are included in the ρ-median problem, prohibition of the assignment of an arbitrary number of demand centers to a given supply center is implied. For example, if $\hat{b_i}$ is the maximum demand (total population to be served or facility capacity) that a supply center located at demand center i can serve, then the following constraint must be included:

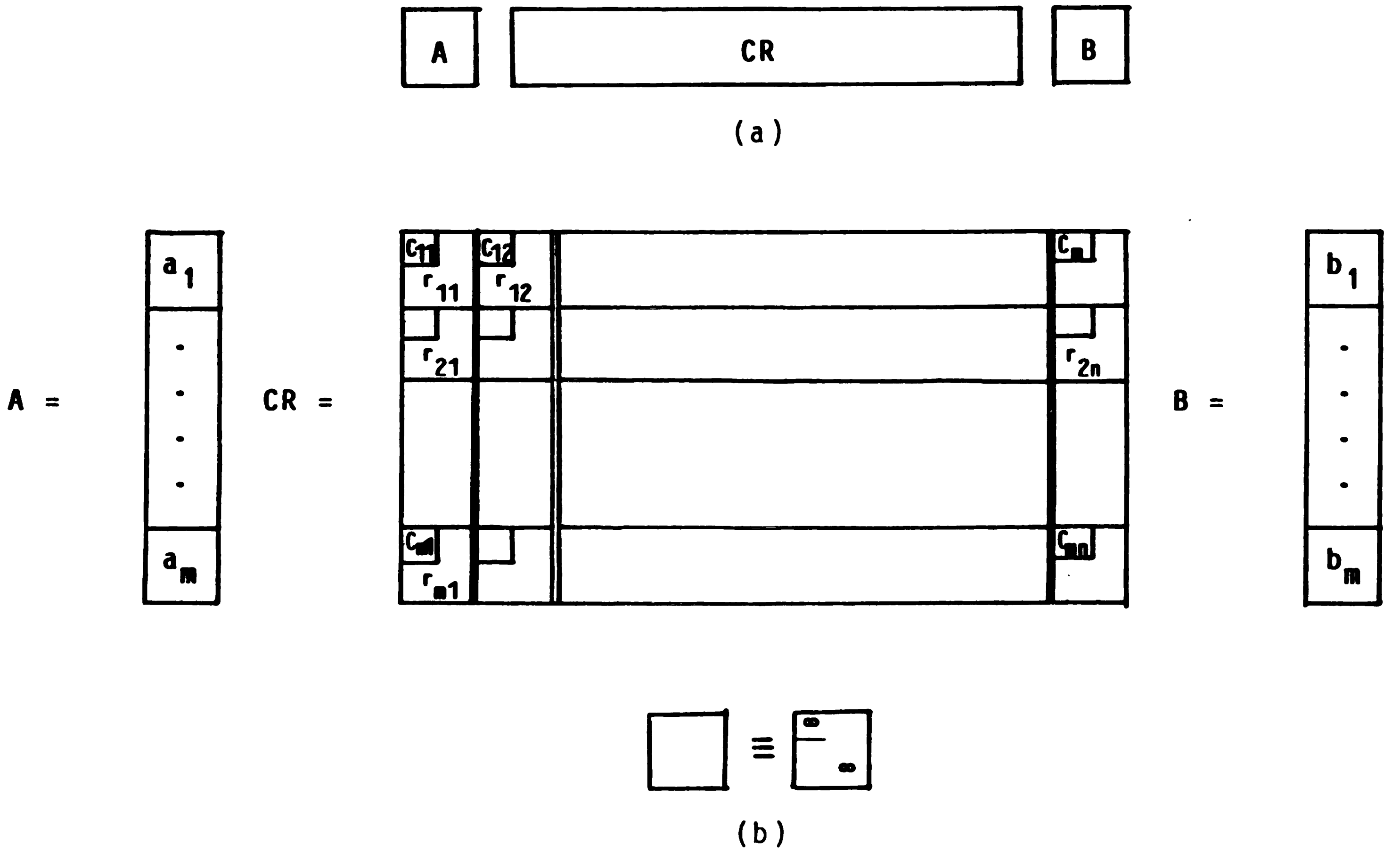


Figure 2.18. Tableau Representation of a Generalized Assignment Problem (GAP).

(a) The overall structure. (b) The detailed structure.

0	$\boxed{C_{11}}$ 1	$\boxed{C_{12}}$ 1	$\boxed{C_{13}}$ 1	$\boxed{0}$ 3			3
0	$\boxed{C_{21}}$ 1	$\boxed{C_{22}}$ 1	$\boxed{C_{23}}$ 1		$\boxed{0}$ 3		3
0	$\boxed{C_{31}}$ 1	$\boxed{C_{32}}$ 1	$\boxed{C_{33}}$ 1			$\boxed{0}$ 3	3
0				$\boxed{0}$ 1	$\boxed{0}$ 1	$\boxed{0}$ 1	2

Figure 2.19. GAP Tableau Representation of a ρ- Median Problem.

($N=3$, $\rho=2$)

NOTES:

(i) Each demand center is a potential location for a supply center.

(ii) Requirement: Choose ρ of N demand center locations ($0<\rho<N$) to be supply centers.

(iii) $a_i=0$; $b_i=N$; $i=1,2,\ldots,N$

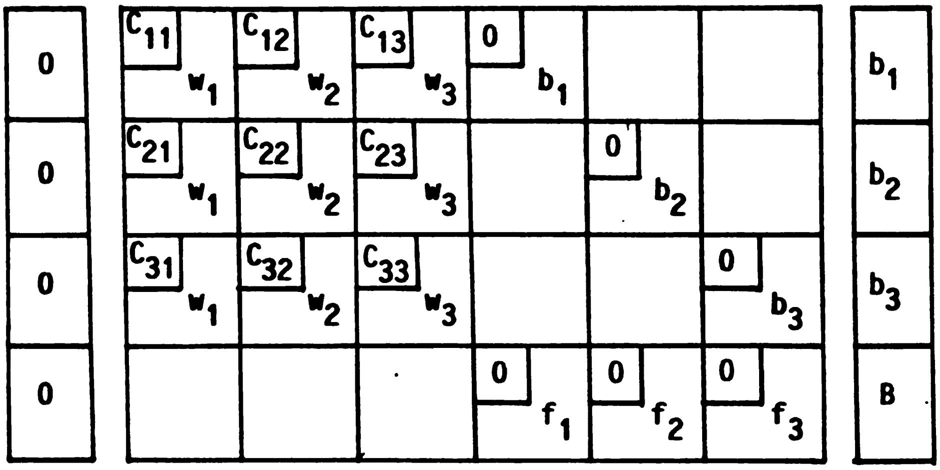
$a_{N+1} = b_{N+1} = \rho$

$C_{ij} = C_{\hat{ij}} = w_j t_{ij}$; $r_{ij} = 1$; $i,j = 1,2,\ldots,N$

$C_{i,N+i} = 0$; $r_{i,N+i} = N$; $i = 1,2,\ldots,N$

$C_{N+1,N+i} = 0$ $r_{N+1,N+i} = 1$; $i = 1,2,\ldots,N$

$C_{ij} = r_{ij} = \infty$ otherwise



0	C_{11} w_1	C_{12} w_2	C_{13} w_3	0 b_1			b_1
0	C_{21} w_1	C_{22} w_2	C_{23} w_3		0 b_2		b_2
0	C_{31} w_1	C_{32} w_2	C_{33} w_3			0 b_3	b_3
0				0 f_1	0 f_2	0 f_3	B

Figure 2.20. GAP Tableau Representation of a Median Problem with Capacity and Investment Constraints.

$(N=3., b_i \equiv b_{\hat{i}})$

i.e., $\sum_{j\varepsilon J} w_j x_{ij} \leq b_{\hat{i}}$ [2.26]

This is then incorporated into the GAP formulation by changing the GAP parameters as follows:

$b_i = b_{\hat{i}}$ $\forall_i$ [2.27]

$r_{ij} = w_j$ $\forall_{i,j}$ [2.28]

and:

$r_{i,N+i} = b_{\hat{i}}$ $i = 1,2,\ldots,N$ [2.29]

When investment restrictions are included in the ρ-median problem, the assumption then is that the fixed investment expense is incurred only if the demand center is designated a supply center. As pointed out by Revelle and Swain (1970) and Rojeski and Revelle (1970), restriction on the number of supply centers to ρ amounts to an investment constraint that all supply centers require the same level of investment. The investment constraint that the sum of the fixed investment expenses (f_i) does not exceed a budgetary level B is easily incorporated into the GAP formulation by changing GAP parameter specifications as follows:

$A_{N+1} = 0,$ $a_{N+1} = B$

$r_{N+1,N+i} = f_i$ $i = 1,2,\ldots,N$

For location of emergency facilities, it is often desirable to limit the maximum travel time or distance between a demand center and its assigned supply center (Khumawala, 1973; Toregas, et al., 1971). This is usually accomplished by defining $C_{ij} = r_{ij} = \infty$ for all (i,j) combinations for which t_{ij} exceeds the allowable maximum.

Most private sector models involve distribution systems in which either the demand centers represent customers and the supply centers represent facilities or else the demand centers represent warehouses and the supply centers represent plants. In all cases, the objective is to select supply center locations and/or a distribution schedule in order to minimize a total cost. For N demand centers (j=1,2,...,N) and M potential supply centers (i=1,2,...,M), let:

w_j = demand level of demand center j

f_i = fixed cost incurred to establish a supply center at site i

v_i = cost to process one unit at supply center i

x_{ij} = fraction of the demand of demand center j supplied by supply center i

$t_{ij}(w_i x_{ij})$ = transportation cost for the units sent from supply center i to demand center j

$H(Y) = 1$ if $Y > 0$

$= 0$ if $Y \leq 0$

The problem may then be formulated as:

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$$\text{Minimize } \Sigma_{i=1}^{M}[f_i H(\Sigma_{j=1}^{N} w_j x_{ij}) + V_i \Sigma_{j=1}^{N} w_j x_{ij} + \Sigma_{j=1}^{N} t_{ij}(w_j x_{ij})] \quad [2.30]$$

subject to:

$$\Sigma_{i=1}^{M} x_{ij} = 1 \qquad j = 1,2,\ldots,M \qquad [2.31]$$

and:

$$x_{ij} \geq 0 \qquad [2.32]$$

Assuming that t_{ij} is concave, resulting in a concave function, it is observed (Langwill, 1968) that there exists an optimal solution in which all x_{ij} are 0 or 1, i.e., each demand center has a unique supply center associated with it. Further, one can use the definitions:

x_{ij} = 1 if demand center j is assigned to supply center i

= 0 otherwise

$C_{\hat{ij}} = V_i w_j + t_{ij}(w_j)$

and the objective function then becomes:

$$\Sigma_{i=1}^{M}[f_i H(\Sigma_{j=1}^{N} w_j x_{ij}) + \Sigma_{j=1}^{N} C_{\hat{ij}} x_{ij}] \qquad [2.33]$$

In the formulation of this as a GAP, the x_{ij} are as defined above where i=1,2,...,M and j=1,2,...,N. As in the ρ-median problem described above, an additional "task" is used to specify whether or not each of the M sites is designated a supply center. One additional "agent" is also required;

therefore, the GAP is of size $m = M+1$ by $n = N+1$. For $i \leq M$, additional variables need to be defined. Thus:

$$x_{M+1,N+i} = 1 \text{ if site } i \text{ is designated a supply center}$$
$$= 0 \text{ otherwise}$$

$$x_{i,N=i} = 1 - x_{M+1,N+i}$$

All other x_{ij}'s for $j > N$ must be zero, and all x_{ij}'s for $i = N+1$ must be zero. The remainder of the GAP formulation requires complete specification of the r_{ij}, A_i, B_i, and C_{ij}. Figure 2.21 illustrates the structural representation of the problem.

Generalization of the above simple facility location problem involves additional constraints usually on the allowable supply center configurations and on the allocations. Where a maximum number of units that may be furnished by supply center i is $b_i^{\hat{}}$, in general, there will not exist an optimal solution in which the total requirement of each demand center is met by only one supply center. This is often a very desirable solution property (Geoffrion, 1975).

Figure 2.22 is the representation of the capacitated facility location problem with two configuration constraints formulated as GAP. The last row of the GAP tableau may be used to impose configuration constraints other than one restricting the number of supply centers. In this example, the last row stipulates a restriction that at

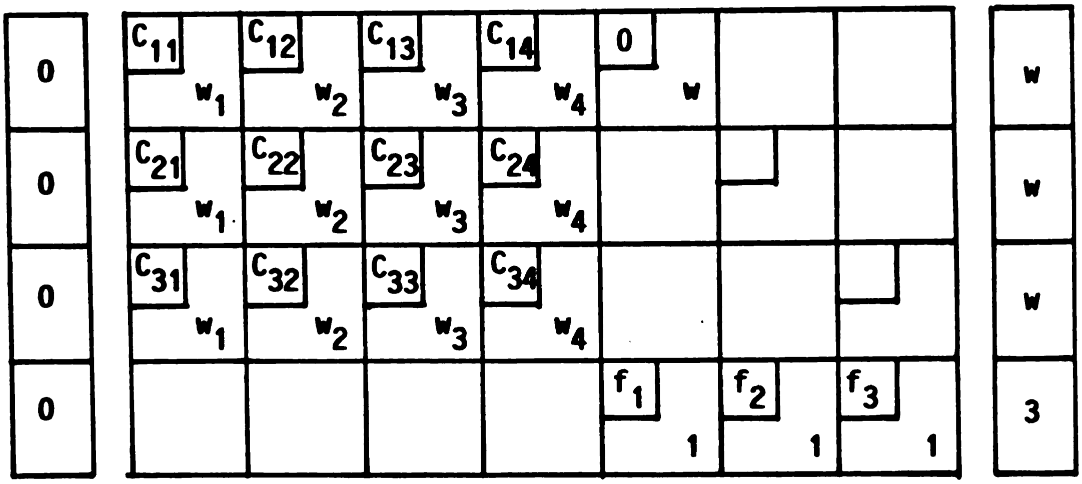

Figure 2.21. GAP Tableau Representation of a Simple Facility Location Problem.

NOTE: $a_i = 0$; $b_i = w$; $i = 1,2,\ldots,M$

$a_{M+1} = 0$; $b_{M+1} = M$;

$C_{ij} = C_{ij}$; $r_{ij} = w_j$; $i = 1,2,\ldots,M$
$j = 1,2,\ldots,N$

$C_{i,N+1} = 0$ $R_{i,N+1} = w$; $i = 1,2,\ldots,M$

and

$C_{ij} = r_{ij} = \infty$ otherwise

a_1	c_{11} w_1	c_{12} w_2	c_{13} w_3	c_{14} w_4	0 b_1				b_1
a_2	c_{21} w_1	c_{22} w_2	c_{23} w_3	c_{24} w_4		0 b_2			b_2
a_3	c_{31} w_1	c_{32} w_2	c_{33} w_3	c_{34} w_4			0 b_3		b_3
a_4	c_{41} w_1	c_{42} w_2	c_{43} w_3	c_{44} w_4				0 b_4	b_4
1					f_1 1	f_2 1			2
2							f_3 2	f_4 2	1

Figure 2.22. GAP Tableau Representation of Capacitated Facility Location Problem.

(M=N=4 and Two Configuration Constraints)

NOTES:

(a) Changes to simple facility parameter specifications are:

set $r_{i,N+i} = b_i = b_i^{\wedge}$ $\quad$ $i = 1,2,\ldots,M$

(b) Forcing supply center at i to furnish at least a_i units:

set $a_i = a_i^{\wedge}$ $\quad$ $i = 1,2,\ldots,M$

(c) Number of supply centers may be limited to the interval (ρ_1, ρ_2) by specifying $a_{M+1} = \rho_1$ and $b_{M+1} = \rho_2$.

(d) Proper treatment of transportation costs requires the assumption that function t_{ij} is linear.

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least one of the first two sites be used and that at most one of the last two sites be used. The GAP size in this case is m = M+2 by n = N+1 (Ross and Soland, 1977).

A number of algorithms have been developed for the problem of locating facilities (medians) on a network so as to minimize the sum of all the distances from each vertex to its nearest facility. Linear programming-based approaches have been outlined by Spielberg (1969), Garfinkel, et al. (1974), and Schrage (1975). Heuristic methods similar to one by Maranzana (1964) have also been outlined by Teitz and Bart (1968). Tree search procedures, such as those by Efroymson and Ray (1966), have also been utilized by Khumawala (1972) and Christofides and Beasley (1982). The latter utilizes the lagrangean relaxation in conjunction with subgradient optimization of lower bounds to be used in tree search procedures.

The lagrangean relaxation method for solving integer programming problems puts into use the observation that many hard integer programming problems can be viewed as easy problems complicated by a relatively small set of side constraints. Dualizing the side constraints produces a lagrangean problem that is easy to solve and whose optimal value is a lower bound (for minimization problems) on the optimal value of the original problem. The lagrangean problem can thus be used in place of a linear programming relaxation to provide the bounds in the branch-and-bound algorithm (Fisher, 1981).

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Held and Karp (1970) used a lagrangean problem based on minimum spanning trees to devise a dramatically successful algorithm for the traveling salesman problem. Fisher (1973) used lagrange multipliers in solving scheduling problems, and Geoffrion (1974), who coined the name "lagrangean relaxation," demonstrated the use of the procedure in integer programming and later applied the procedure to capacitated facility location problems (Geoffrion and McBride, 1978). For most of these problems, lagrangean relaxation has provided the best existing algorithm for the problem and has enabled the solution of problems of practical size (Fisher, 1981). Appendix G outlines the general description and basic structure of lagrange multiplier techniques and an example demonstrating its use. It should be noted, however, that it is often essentially impossible to solve the set of nonlinear equations involved in the lagrange multiplier method to obtain the critical (local and global minimum, maximum, and inflection) points. Even when they can be obtained, the number of critical points may be so large (often infinite) that it is impractical to attempt to identify global minimum or maximum except for certain types of small problems (Hillier and Lieberman, 1980).

Most of the work outlined above dealt with static solution to location problems. As a result of the stochastic nature of most practical location problems, a multiperiod focus on such problems has, in some cases, been found useful and desirable.

2.5. Multiperiod Location Analysis

Several papers have dealt with multiperiod or dynamic aspects of the discrete space location-allocation problem. The goal has, in most cases, been to devise a plan of optimal locations and relocations in response to predicted changes in the demand volume originating at demand points over a planning horizon. The intention is to avoid "myopic" relocations which, being based on current demands only, may not be optimal.

Ballou (1968) and Wesolowsky (1973) have dealt with single facility multiperiod location problems. Klein and Klimpel (1967) applied dynamic programming to a fixed charge problem under economies of scale. Scott (1971) treated a case where facilities can enter the system one at a time with relocations allowed. Tapiero (1971) dealt with a continuous space, capacitated problem under a continuous time horizon. Gunawardane (1981) considered several multiperiod public facility planning decision problems such as multiperiod service coverage, multiperiod service phaseout, and multiperiod maximum coverage. Roodman and Shwarz (1975, 1977) looked at the multiperiod facility phaseout and phasein models.

Wesolowsky and Truscott (1975) extended the usefulness of single period models by Revelle and Swain (1970) by introducing dynamic considerations. Shifts in the pattern of demand over a planning horizon may warrant a multiperiod analysis which investigates the tradeoffs between static distribution costs and expenditures for relocating facilities. If positive relocation costs are associated with both the vacating of a site and the entering of a site, then the dynamic model may be formulated as follows:

$$\text{Minimize } \Sigma_{k=1}^{K}\Sigma_{i=1}^{N}\Sigma_{j=1}^{M} A_{ijk}x_{ijk} + \Sigma_{k=2}^{K}\Sigma_{j=1}^{M}(C'_{jk}Y'_{jk} + C''_{jk}Y''_{jk}) \quad [2.34]$$

subject to:

$$\Sigma_{j=1}^{M}x_{ijk} = 1 \qquad \text{for } i = 1,2,\ldots,N;\ k = 1,2,\ldots,K \quad [2.35]$$

$$\Sigma_{j=1}^{M}x_{ijk} \leq Nx_{jjk} \qquad \text{for } j = 1,2,\ldots,M;\ k = 1,2,\ldots,K \quad [2.36]$$

$$\Sigma_{j=1}^{M}x_{jjk} = G \qquad \text{for } k = 1,2,\ldots,K \quad [2.37]$$

$$\Sigma_{j=1}^{M}Y'_{jk} \leq m_k \qquad \text{for } k = 2,3,\ldots,K \quad [2.38]$$

$$x_{jjk}-x_{jj,k-1}+Y'_{jk}-Y''_{jk}=0 \qquad \text{for } j = 1,2,\ldots,M;\ k = 2,3,\ldots,K \quad [2.39]$$

and:

$$\text{all } x_{ijk} \text{ for } i \neq j \ : \ Y'_{jk}, Y''_{jk} \geq 0 \quad [2.40]$$

$$\text{all } x_{jjk} = 0 \text{ or } 1 \quad [2.41]$$

where:

A_{ijk} = the present value (PV) of the cost of assigning node i to node j in period k

C'_{jk} = the present value of the cost of removing a facility from site j in period k

C''_{jk} = the PV of the cost of establishing a facility at site j in period k

m_k = the maximum number of facility location changes allowed in period k

N = number of demand points

G = number of facilities to be allocated among M modes

K = planning horizon periods

x_{ijk} = 1 if node i is assigned to node j in period k
= 0 otherwise

Y'_{jk} = 1 if facility is removed from site j in period k
= 0 otherwise

Y''_{jk} = 1 if a facility is established a site j in period k
= 0 otherwise

Note that constraints set [2.38] limits the number of sites vacated in each of period 2 through k reflecting the tolerable level of organizational disruption. The constraint set [2.39] ensures that appropriate relocation charges are charged. The mixed integer formulation of this dynamic problem in [2.34] to [2.41] has the following size characteristics:

Number of constraints = K(N+2M+2)-M-1
Number of continuous variables = K[M(N+1)]-2M
Number of binary variables = KM

In solving the multiperiod model above using a dynamic programming approach, the stages are the planning horizon periods, the states are the facility configurations, and decisions are choices of location changes. Dynamic programming is a particularly attractive solution technique (over integer programming) for the model when the state space is quite limited by the relative value of G and M and the scope of decisions is contained by small values of m_k.

In both static and dynamic location problems, the emphasis has always been to devise a single system plan for location and relocation of facilities. Little has been done in trying to produce alternative plans to cater to unspecified issues that may be important but difficult to include in the formulations. Planning alternatives are useful in the planning and decision-making process.

2.6. Generating Planning Alternatives

Creativity and inventiveness are important ingredients for generating good alternative solutions to public problems. The total feasible space is rarely known, since the feasible space considered in a typical mathematical model is too limited. An optimization model does, however, offer the potential for promoting invention within its feasible space and provide assistance in evaluating and elaborating selected alternatives. Brill (1979), elaborating the use of optimization models as tools within a planning process, reflected on some important elements of conventional planning approaches (Figure 2.23).

Brill and Nakamura (1978) and Nakamura and Brill (1979) developed a branch-and-bound method specifically for the purpose of generating and comparing alternative plans for use in locating regional wastewater treatment facilities. Their algorithm, by making some trivial calculations, was designed such that each node solution in the branch-and-bound tree was used to provide alternative solutions. The next step was to use the information contained in the branch-and-bound tree to compare alternative solutions. Since many issues associated with developing a plan were related to specific facilities, their method was extended to calculate cost savings or imputed values between the "least cost" plan that contained a given facility (or set of facilities) and the "least cost" plan that did not. Brill, et al. (1976) reported the use of trade-off curves determined using optimization models as one method for obtaining different plans.

One cannot a priori specify a path that will lead to truly inventive solutions to complex public problems. For such use, optimization models should be capable of generating alternative solutions that meet minimal requirements (including minimal targets for all objective functions formulated as constraints) and are different. Brill, et al. (1982) outlined some possible approaches and their drawbacks to modeling to generate alternatives which included:

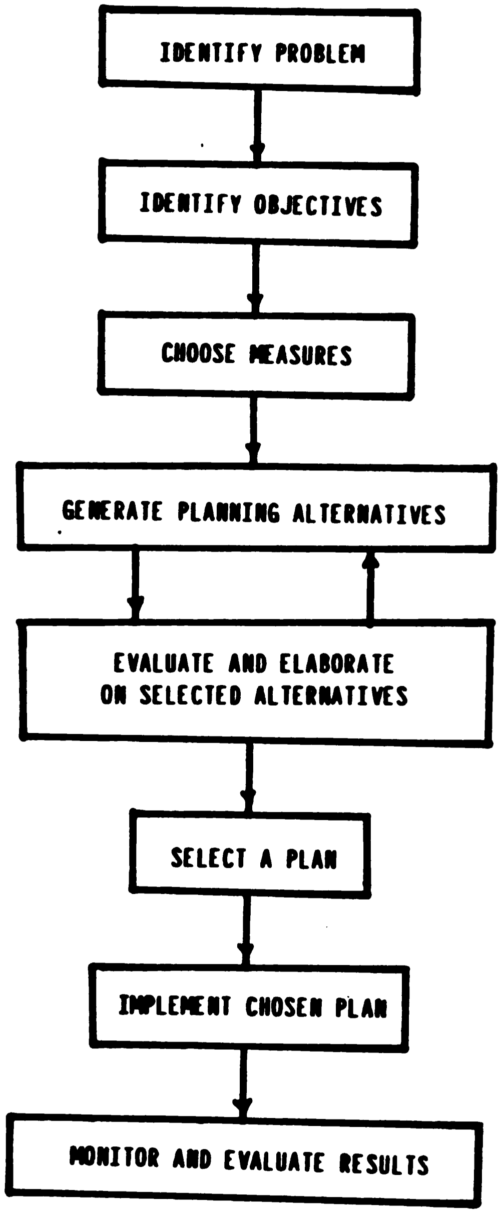


Figure 2.23. Elements of a Planning Process.

Notice the double directed stages of generating planning alternatives and their evaluation and elaboration.

(a) Generating planning alternatives using random methods (Brooks, 1958; 1959). Generally, if one is faced with formulations that have many mathematical constraints, it is difficult to randomly generate a set of values of decision variables such that the solution is feasible.

(b) Changing model parameters or equations judgmentally to examine alternative sets of conditions and generate alternative solutions. This is an ad hoc approach and provides no guarantee for obtaining different solutions directly that are different.

(c) Explicitly examining alternative feasible solutions that are routinely generated as part of an optimization algorithm, for example, the branch-and-bound algorithm method by Nakamura and Brill (1979). This approach, however, does not have specific guiding features for producing solutions that are different in decision space.

(d) Obtaining near optimum in a mathematical sense. In spite of the apparent potential use of this approach, the limitation appears to be that within a given region in objective space the procedure does not seem to generate anything different from the preceding solution. Church and Huber (1979) used a measure of difference based on one initial solution to obtain near optimum configurations for single and multiple objective location problems.

(e) Obtaining alternate optima, if they exist, as in linear programming problems with degenerate dual solutions. Searching only for alternate optima, however, restricts the search for alternate solutions. Also, if there are many alternate optima, then it would be cumbersome to search them exhaustively to produce a small set of alternatives that are different.

(f) Generating local optima through gradient search from different starting points generated at random. This approach can only be followed if there are local optima in the first place. Furthermore, other than starting at random points, there is no guiding principle for producing final alternatives that are different.

(g) Using different representations and/or different algorithms to solve the problem. This approach appears interesting, relatively unexplored, and most likely difficult to generalize.

A major limitation of the methods described above is that they do not appear to be general purpose procedures for handling wide classes of problems. One promising method that may be applied to a wide range of problems and designed to explore the full range of differences among solutions with respect to the values of decision variables is that developed by Brill (1979) and illustrated by Chang, et al. (1979). The approach is called HSJ for Hop, Skip, and Jump.

2.6.1. The HSJ Method

Brill, et al. (1982) outlined in brief and in its simplest form the HSJ approach. For a facility location planning problem, viewed as a mixed integer programming problem, the formulation for a single objective—in this case, cost minimization—can be stated as:

$$\text{Minimize } C_1Y + C_2X \qquad [2.42]$$

subject to:

$$A_1Y + A_2X = B \qquad [2.43]$$

where:

Y = the vector 0,1 decision variables associated with the existence of facilities

X = the vector of continuous variables that specify facility capacities

C_1 = the vector of fixed cost coefficients for the 0,1 decision variables

C_2 = the vector of the unit cost coefficients for the continuous decision variables

A_1 = the constraint coefficient matrix for the 0,1 decision variables

A_2 = the constraint coefficient matrix for the continuous decision variables

B = the vector of right-hand-side values

The initial solution can be obtained by solving the formulation above directly. To obtain a second HSJ solution, the sum of the basic nonzero decision variables in the first solution are then minimized, subject to the original constraints. The cost is relaxed an acceptable amount relative to the best possible value and specified as an additional constraint. This formulation is then capable of producing a solution that is adequately different from the initial solution.

The second HSJ formulation may be obtained by solving the following formulation:

$$\text{Minimize } \sum_{b \varepsilon K} Y_b + \sum_{b \varepsilon K} X_b \qquad [2.44]$$

subject to:

$$C_1 Y + C_2 X \leq T \qquad [2.45]$$

<u>and</u> constraint set defined by Equation 2.43, where:

Y_b, X_b = the basic variables in the initial solution

K = the set of indices of the nonzero variables in the initial solution

C_1Y+C_2X = the cost objective function

T = the relaxed cost where T = C*+a

C* = cost obtained by solving initial solution

a = the amount the cost is relaxed from C*

To obtain succeeding alternatives, a formulation similar to the latter is used except that the nonzero variables in the

HSJ objective function should include all the nonzero variables in all preceding solutions. This procedure continues until no more alternatives can be obtained or enough different solutions have been generated.

In the case of multiobjective mixed integer programming problem formulations, the HSJ procedure is the same as described above except that:

(a) The initial solution may be obtained in several ways, including:
    (1) minimizing the weighted sum of all objectives subject to original constraints,
    (2) minimizing one objective subject to the original constraints as well as constraints that specify targets for other objectives, or,
    (3) minimizing one objective subject to the original constraints without placing constraints on any other objective.

(b) Target on some or all objectives can be relaxed an acceptable amount and treated as additional constraints when solving formulations defined by Equations 2.44 and 2.45.

2.6.2. Estimating Differences Among Alternatives

The measurement of differences among alternative solutions is necessary in order to eliminate solutions that are similar. The concept of differences among alternatives, however, is vague, and there is no one perfect measure. The methods that have been used to calculate pairwise differences between solutions are:

(a) Calculating the number of different nonzero variables between two solutions. This method does not provide one with figures that reflect the difference caused by a change in decision variables.

(b) Calculating the sum of absolute differences in decision variable values between two solutions (Chang, et al., 1981; Brill, et al., 1982), i.e., between n and n+1 as:

$$\Sigma_j |x_{jn} - x_{j,n+1}|$$

where x_{jn} is the jth decision variable in solution n.

(c) Calculating the imputed values in cases where a plan being developed is related to specific facilities such that it is required to determine the cost savings between the least cost plan that contains a given facility (or a set of facilities) and the least cost plan that does not (Nakamura and Brill, 1979).

(d) Visual inspection is particularly useful in locational analysis in an effort to analyze the regional configuration of facilities (Chang, et al., 1981).

Since each method has its advantages and disadvantages and none is perfect for all cases, in many situations, all methods have been used to provide more insight into problems being investigated.

CHAPTER 3

MODEL DEVELOPMENT

3.1. Methodological Choices in Facility Location Studies

Francis and Goldstine (1974) published a selective bibliography of location studies listing about 226 papers, but this list is certainly not exhaustive. This creates some difficulties for the practitioner who is trying to discover in the published literature a way in which he should tackle his particular problem. The most important choices that have been considered in this work, and indeed in many other facility location studies, are those outlined by Rand (1976), which include:

(1) Objective: cost minimization or return-on-assets criteria?

(2) Potential Locations: anywhere (infinite set) or particular sites (feasible set)?

(3) Search Procedure: optimizing or heuristic?

(4) Planning Horizon: this year or sometime . . . ?

(5) Existing Facilities: to be included or not?

In facility location studies, the aim has typically been to minimize costs; however, a total set approach to distribution requires that individual cost elements be considered in relation to total costs. Figure 3.1 shows schematically the effect of changes in facility costs on other cost elements in the distribution system using hypothetical data. A similar diagram is hypothesized by Beattie (1973). Where the firm has competing projects and limited resources, objective function formulation based on the return-on-investment criteria is a more useful approach.

The choice between finite and infinite set approaches is influenced by the main features of each approach. Eilon, et al. (1971) list the main features of the two approaches as follows:

(a) The Infinite Set Approach:

—does not require the locations which are selected to be *a priori* attractive.

—is flexible in that it examines a monotonic function.

—alternative solutions are available in multisite selection problems.

—a solution may involve a nonfeasible location, e.g., swamp.

—transport costs may be a monotonic function of distance.

(b) The Feasible Set Approach:

—incorporates costs which are related to specific geographical locations.

—does not require transport costs to be any function of distance.

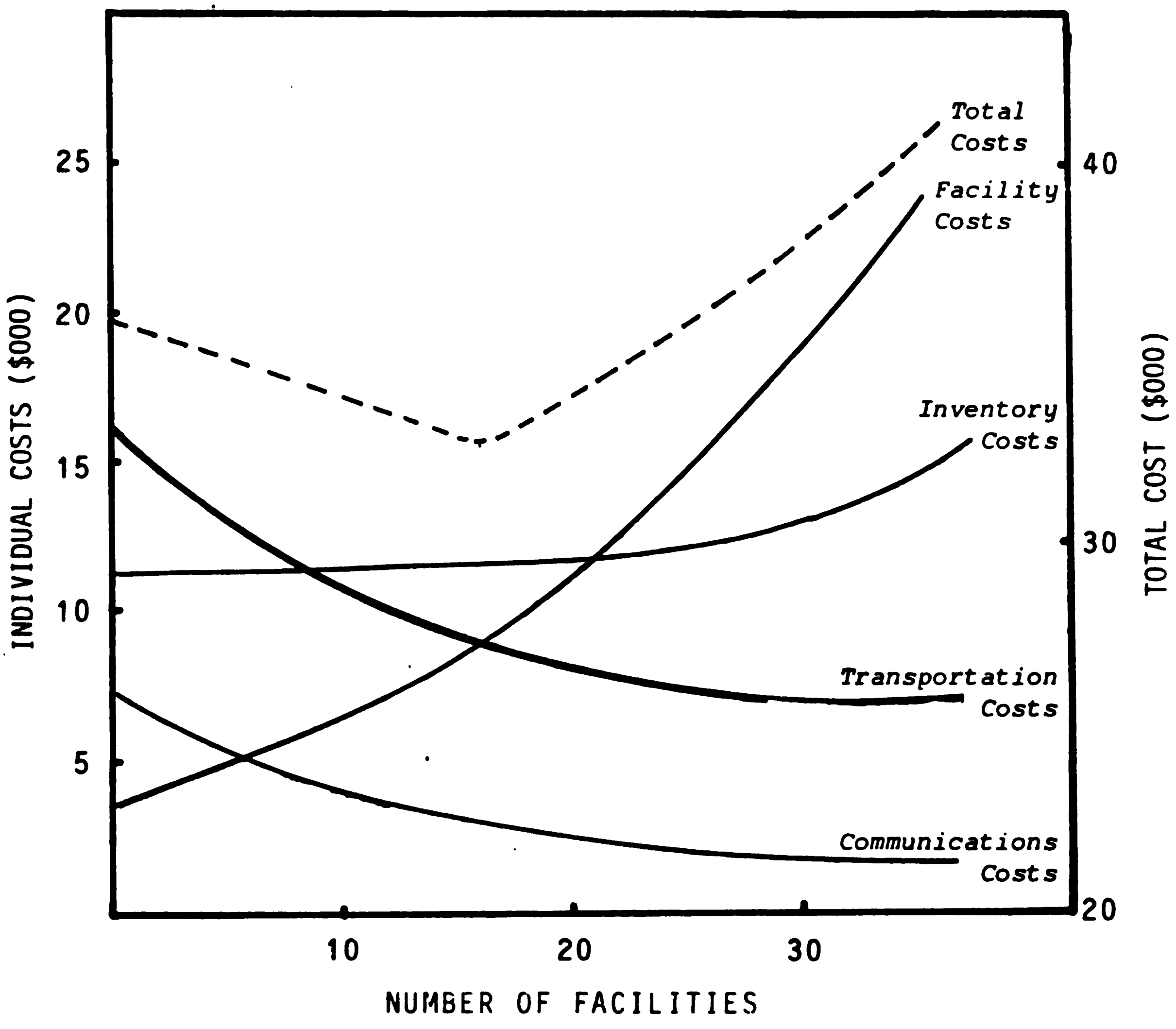


Figure 3.1. Effects of Number of Facilities on Cost Elements of a Distribution System.

—requires a set of sites which are known to be feasible and for which all cost data are available.

—the number of locations must be finite and sufficiently small for computational efficiency.

—the set of feasible sites may not contain the optimum solution.

Eilon, et al., favor the infinite set approach. However, several criticisms can be said about this approach. It will not guarantee finding an optimal (or near optimal) solution. A common algorithm used in the infinite set approach necessitates generation of many solutions with different starting points in order to choose the best solution. There is no procedure, apart from enumeration, for determining the number of facilities. And, as indicated in the main features outlined above, it is possible to obtain a solution giving nonfeasible sites (a factory site on top of Mount Kilimanjaro!).

The usual criticism of the feasible set approach is the large number of possible locations needing to be specified in order to ensure a solution which is reasonably close to optimum. Fortunately, due to usually very shallow objective functions near the optimum, the physical site can be chosen in a reasonably large area near the solution site specified without moving far from the theoretical optimal cost.

Coupled with the choice between finite and infinite set approaches is the choice of the mathematical algorithm (search procedure). In practice, there is inevitably a trade-off between the complexity of the search procedure and sophistication of the cost functions. The choice can usually be presented in diagram form as in Figure 3.2.

On the planning horizon, most early studies were concerned with static situations based on one demand pattern. In recent studies, however, some emphasis has been placed on multiperiod analysis. In this study, it is believed that to provide a plan for the entire planning horizon the data generation for predicting the future has to be efficient and robust. One other suggested approach is to consider the robustness of locations to possible futures (Rosenhead, et al., 1972).

On the need to determine whether present sites should be included in the analysis or not, very much depends on the arising situation. Very rarely is a management scientist presented with an initial facility location problem (i.e., "greenfields" situation). Usually, the firm will already have a number of facilities located nationally or serving a particular region. The analyst is faced with two choices: one is to include the present sites in the model as a fixed base from which location and relocation are allowed. The other possibility is to find the "greenfields" solution (i.e., ignoring the present sites configuration) and then consider the implementation of the greenfields solution in relation to present locations.

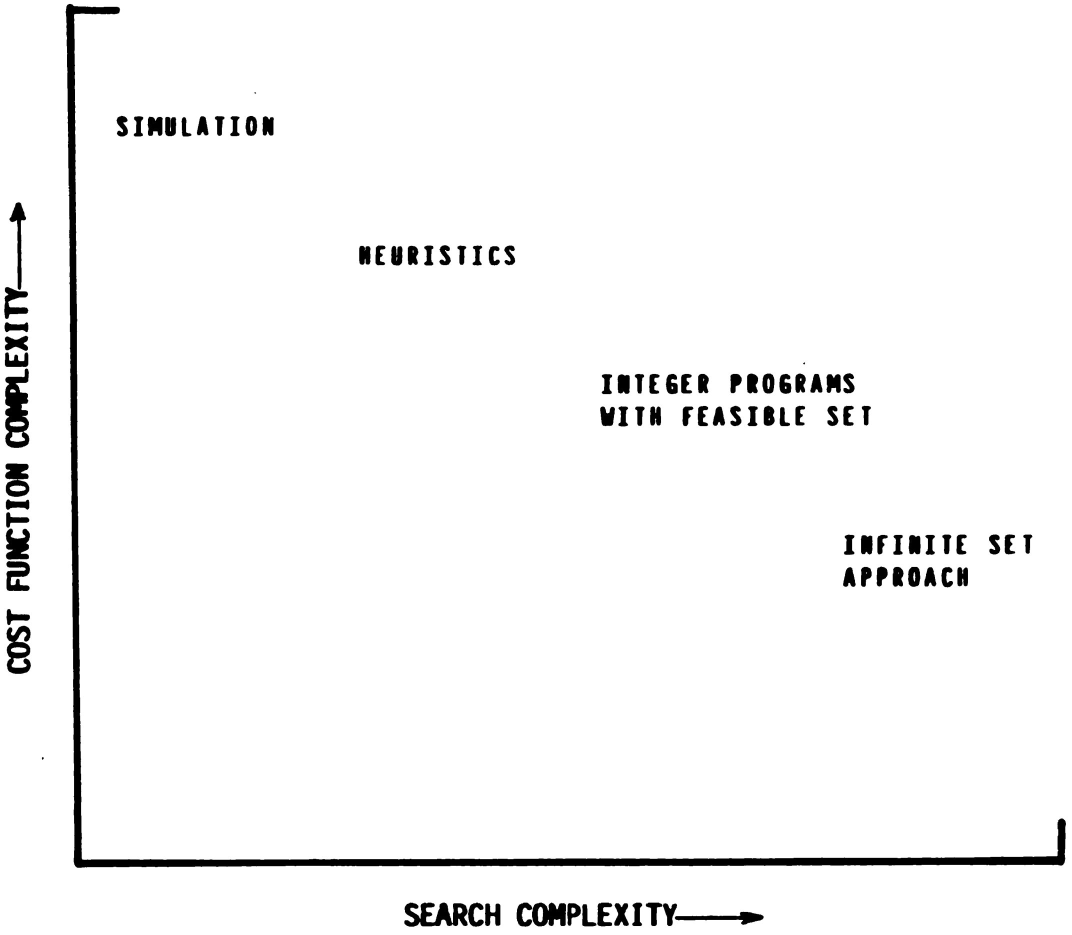


Figure 3.2. Search Procedure Complexity Versus Complexity of Cost Functions.

For example, a simulation model usually has a more complex cost function but with a more straight forward search procedure.

A cost minimization finite location set approach is suggested in this study.

3.2. Model Formulation

3.2.1. Problem Definition and Objective

A finite number of potential cashewnut processing plant sites was available. Each had associated with it known fixed costs and known functional forms of operating costs, should a plant be in operation at that site. A maximum capacity for a plant at each site and the production level at each production center were known or assumed predictable, respectively. The distribution costs consisted of the sum of the fixed costs and operating costs of all processing plants that were actually opened and the transportation costs. The objective of the model was to devise plant location plans that minimized the system distribution cost.

3.2.2. A General Mathematical Formulation

The mathematical formulation of the problem can be presented as follows:

$$\text{Minimize } Z = \Sigma_{i=1}^{m}[F_i Y_i + f_i(\Sigma_{j=1}^{n} x_{ij}) + \Sigma_{j=1}^{n} t_{ij} x_{ij}] \qquad [3.1]$$

subject to facility capacity restrictions (hitherto referred to as "supply restrictions"):

$$\Sigma_{j=1}^{n} x_{ij} \leq Y_i a_i \qquad \text{for } i = 1,2,\ldots,m \qquad [3.2]$$

and subject to customer demand requirements (in this case referring to production center levels):

$$\Sigma_{i=1}^{m} x_{ij} \geq b_j \qquad \text{for } j = 1,2,\ldots,n \qquad [3.3]$$

<u>and</u>:

$$Y_i = 0 \text{ or } 1 \qquad \text{for } i = 1,2,\ldots,m \qquad [3.4]$$

$$X_{ij} \geq 0 \qquad \text{for } i = 1,2,\ldots,m \quad j = 1,2,\ldots,n \qquad [3.5]$$

where:

m = number of potential facility sites

n = number of customer demand centers

t_{ij} = total linear cost per unit of shipping from demand center j to facility i

b_j = demand at customer demand center j

a_i = maximum capacity of facility i

x_{ij} = amount shipped from demand center j to facility i

F_i = fixed cost associated with operating a facility at site i

Y_i = variable denoting the establishment of a facility at site i (Y_i=1) or absence of a facility at site i (Y_i=0)

$f_i(\cdot)$ = nonlinear operating cost, exclusive of fixed cost, associated with a facility at site i

Special cases of this problem (already referred to in the literature review) have been treated extensively. Some of the cases can be summarized as follows:

(a) If $F_i = f_i(\cdot) = 0$ and $Y_i = 1$ for all i's, the above formulation reduces to a simple transportation problem.

(b) If $f_i(\cdot) = 0$ and a_i is infinite for all i's, the problem becomes an uncapacitated facility location problem which has been solved using heuristics (Kuehn and Hamburger, 1963; Feldman, et al., 1966; Khumawala, 1973) and optimizing solution techniques (Erlenkotter, 1978; Khumawala, 1972; Sá, 1969; Soland, 1974). Small values of a_i which result in a capacitated facility location problem have been accommodated in principle by existing programming techniques, but such methods are not yet computationally efficient for most practical problems (Sá, 1969; Davis and Ray, 1969; Ellwein and Gray, 1971; Akine and Khumawala, 1977).

(c) Cases where $F_i = 0$, a_i is infinite, and $f_i(\cdot)$ is semicontinuous, piecewise linear for all i's, have been tackled using both optimizing and approximation solution methods (Feldman, et al., 1966).

(d) Cases where $f_i(\cdot)$ is concave and continuous or semicontinuous or has a finite number of discontinuities have been addressed successfully theoretically, but optimal solution techniques have not been demonstrated to be practical.

(e) Heuristic approaches to the case where $f_i(\cdot)$ has a functional form:

$$K_i(\Sigma_{j=1}^{n} x_{ij})^q$$

where $0 < q < 1$ have been used to solve fairly large problems where no capacity restrictions on facilities are imposed (Khumawala and Kelly, 1974).

3.2.3. Mathematical Formulation: Cashewnut Industry Problem

A mixed integer formulation of cashew processing and handling problems with an objective of minimizing costs is:

(1) $$\text{Minimize } Z = TC_1+TC_2+TC_3+TC_4+CPC \qquad [3.6]$$

subject to:

(2) Each production center, j (j=1,2,...,n), sends its raw nut production, RN_j, to one and only one processing plant:

$$Z_{ij} = 1 \quad \text{if production center } j \text{ is allocated to plant } i \qquad [3.7]$$

$$= 0 \quad \text{otherwise} \qquad [3.8]$$

and:

$$\Sigma_{zij} = 1 \qquad \forall_i \qquad [3.9]$$

This constraint is later relaxed in solving the problem.

(3) The capacity of the processing plant, i (i=1,2,...,m), PC_i, should not exceed some maximum value, PC_{max}:

$$PC_i = \Sigma_{j=1}^{n} RN_j z_{ij} \leq PC_{max} \qquad \forall_i \qquad [3.10]$$

(4) The amount of rawnuts supplied to export depot, p (p=1,2,...,k) by the processing plant i, RN_{ip}, equals the amount of rawnuts processed by the processing plant:

$$\Sigma_{p=1}^{k} RN_{ip} = \Sigma_{j=1}^{n} v_i RN_j z_{ij} \qquad \forall_i \qquad [3.11]$$

where v_i is the proportion (decimal) of total rawnuts procured by processing plant i that are processed to be sold as rawnuts.

(5) The amount of kernels supplied to each export depot, p (p=1,2,...,k) by the processing plant i, K_{ip}, equals the amount of kernels processed by that processing plant:

$$\Sigma_{p=1}^{k} K_{ip} = \Sigma_{j=1}^{n} q_j (1-v_i) RN_j \qquad \forall_i \qquad [3.12]$$

where q_j is the weight (kg) of processed kernels per unit weight of rawnuts supplied to that processing plant.

(6) The total amount of CNSL supplied to export depot, p ($p=1,2,\ldots,k$) by processing plant i, SL_{ip}, equals the amount of cashewnut shell liquid extracted from raw cashew shells supplied to that processing plant:

$$\Sigma_{p=1}^{k} SL_{ip} = \Sigma_{j=1}^{n} (1=v_i) r_i RN_j \qquad \forall_i \qquad [3.13]$$

where r_i is the amount (kg) of CNSL extracted from a unit of rawnuts supplied to that plant.

(7) $$RN_j,\ K_{ip},\ \text{and}\ SL_{ip} \geq 0 \qquad \forall_j,\ \forall_i\ \text{and}\ \forall_{i,p} \qquad [3.14]$$

The transportation costs in the objective function equation can be expanded as follows:

Cost of shipping rawnuts from production centers to processing plants:

$$TC_1 = \beta_1 \Sigma_{j=1}^{n} \Sigma_{i=1}^{m} RN_j d_{ij} z_{ij} \qquad [3.15]$$

Cost of shipping processed rawnuts from processing plants to export depot:

$$TC_2 = \beta_2 \Sigma_{i=1}^{m} \Sigma_{p=1}^{k} RN_{ip} d_{ip} z_{ij} \qquad [3.16]$$

Cost of shipping processed kernels to export depot:

$$TC_3 = \beta_3 \Sigma_{i=1}^{m} \Sigma_{p=1}^{k} K_{ip} d_{ip} z_{ij} \qquad [3.17]$$

Cost of shipping CNSL from processing plant to export depot:

$$TC_4 = \beta_4 \Sigma^m_{i=1} \Sigma^k_{p=1} SL_{ip} d_{ip} z_{ij} \qquad [3.18]$$

where β_1, β_2, β_3, β_4 are the return journey unit cost and d_{ij} and d_{ip} are the respective distances from the production center to processing plants and processing plants to export depot.

The cashewnut processing costs, CPC, in the objective function equation can be expanded as follows:

$$CPC = \Sigma^m_{i=1}[F_i Y_i + f_i(\Sigma^n_{j=1} RN_j)] \qquad [3.19]$$

where:

F_i = fixed cost incurred for operating facility at site i

Y_i = 1 if facility i is in operation at site i
= 0 otherwise

$f_i(\cdot)$ = concave variable operating cost function for facility at site i

As formulated above, the cashew industry facility location problem is very similar to the general mathematical formulation outlined in section 3.2.2 for the capacitated facility location problem. Therefore, the facility cost, capacity, and demand data in appropriate units can therefore be included into the cost-per-tonne-per-year matrices, C_{ij}'s, as outlined in tableau form in Table 3.1.

3.3. Background Model Design Data Review

3.3.1. Cashew Production in Tanzania

Figure 1.4 is a map of the cashewnut production regions in Tanzania showing the nineteen production centers, thirteen existing processing plants, and four ports. Only fifteen of the nineteen production centers are potential plant locations. Only two of the four ports can be designated as export depots, Tanga and Dar es salaam.

Figures for 1981-82 estimate the total area under cashews as being about 200,000 hectares. About 400,000 families in over 2,000 villages are involved in cashew production. During the 1981-82 season, Tanzania's processing plants had a maximum operational annual capacity of 97,000 tonnes of raw cashewnuts (Daily News, 1982). The then twelve established processing plants employed about 10,000 people.

Cashewnut production in Tanzania is by smallholder enterprises for which it is mainly a cash crop. In the southeast coastal zone, where cashew production is concentrated, cashews account for about 80% of the peasants' incomes from the export crops and about 60% of the total national cashew crop output. Table 3.2 shows the raw cashewnut procurement from 1973-74 to 1982-83 by region and by production center.

Table 3.1. Tableau Form for Design Data and Transportation Cost Matrix, C_{ij}.*

Processing Plant i		Production Center j						Capacity
i	F_i	1	2	3	. . . .	n-1	n	$a_i(=RN_{max})$
1	F_1	C_{11}	C_{12}	C_{13}	. . . .	$C_{1,n-1}$	C_{1n}	a_1
2	F_2	C_{21}	C_{22}	C_{23}	. . . .	$C_{2,n-1}$	C_{2n}	a_2
3	F_3	C_{31}	C_{32}	C_{33}	. . . .	$C_{3,n-1}$	C_{3n}	a_3
.	.	.	.	.		.	.	.
.	.	.	.	.		.	.	.
.	.	.	.	.		.	.	.
m-2	F_{m-2}	$C_{m-2,1}$	$C_{m-2,2}$	$C_{m-2,3}$	. . . .	$C_{m-2,n-1}$	$C_{m-2,n}$	a_{m-2}
m-1	F_{m-1}	$C_{m-1,1}$	$C_{m-1,2}$	$C_{m-1,3}$	. . . .	$C_{m-1,n-1}$	$C_{m-1,n}$	a_{m-1}
m	F_m	C_{m1}	C_{m2}	C_{m3}	. . . .	$C_{m,n-1}$	C_{mn}	a_m
Demand $b_j(=RN_j)$		b_1	b_2	b_3	. . . .	b_{n-1}	b_n	

*C_{ij} represents the assignment cost coefficient (includes transportation and operating costs); for example, C_{11} is the coefficient for the plant 1, production center 1 combination.

Table 3.2. Raw Cashewnut Procurement, 1973-74 to 1982-83.

PRODUCTION	Metric Tons									
ZONE	73-74	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82	82-83
MTWARA	**70376**	**51445**	**35194**	**37763**	**34274**	**22457**	**14926**	**29043**	**20946**	**15596**
Mtwara	10032	9310	4020	5692	3466	2995	2829	4284	2278	1767
Newala	34947	24314	18421	20834	19843	10226	6458	14753	14437	9506
Masasi	25397	17821	12753	11237	10965	9236	5639	10006	4231	4323
LINDI	**38298**	**29880**	**20969**	**29686**	**15293**	**13121**	**10542**	**16160**	**7567**	**6859**
Lindi	18783	14126	9597	14670	6448	5426	3271	3389	1312	1174
Mtama	-	-	-	-	-	-	3505	6931	2981	3371
Nachingwea	7916	6557	4479	5243	4072	2788	573	2558	1089	812
Liwale	6023	5079	4433	6090	3222	2792	535	1220	1235	935
Kilwa	5576	4118	2460	3683	1551	2115	2658	2062	950	567
RUVUMA	**9695**	**8301**	**4741**	**4750**	**7615**	**5459**	**1938**	**3427**	**3984**	**2147**
Tunduru	9094	7202	4341	4530	6946	5106	1853	3301	3811	2092
Songea	601	1099	400	220	669	353	85	126	173	55
PWANI	**34251**	**25266**	**19585**	**23536**	**12099**	**15607**	**11379**	**9581**	**9631**	**6592**
Kisarawe	21654	15604	11324	15223	8203	11823	7022	6499	6466	4067
Kibaha	-	-	-	-	-	-	1729	709	669	686
Bagamoyo	4396	3883	2043	2211	685	1562	1140	588	618	469
Rufiji	7396	5013	5497	5068	1869	1678	1260	1582	1590	1077
Mafia	805	766	721	1034	1342	544	228	203	288	293
DAR ES SALAAM	**5070**	**5304**	**3620**	**2072**	**1521**	**1247**	**1319**	**956**	**812**	**500**
TANGA	**3261**	**3083**	**2512**	**2112**	**844**	**1569**	**1113**	**1655**	**1033**	**515**
MBEYA	**1029**	**1358**	**927**	**1050**	**376**	**253**	**-**	**6**	**230**	**130**
MOROGORO	**970**	**813**	**508**	**489**	**334**	**148**	**234**	**111**	**99**	**116**
OTHER	**87**	**130**	**35**	**19**	**89**	**1**	**1**	**26**	**24**	**18**
TOTALS	**153037**	**125580**	**88091**	**102588**	**72445**	**59862**	**41452**	**60965**	**44326**	**32473**

Source: CATA figures.

Generally, cashewnut production in Tanzania was on the increase in the decade preceding the drought years of 1973 and 1974. Good husbandry; improvement in seed quality; weeding; timely nut collection; careful drying of nuts; pruning of old, sagging branches; and the peak economic age (12-15 years) of the cashew trees then, accounted for the rising trend in cashewnut production prior to the 1973-74 season. After 1974-75, there was a continuing decline in production (see Figure 3.3). The villagization program, under which most peasants were moved far enough distances that they could not effectively attend to their cashew plots, has been cited as one of the major reasons leading to the decline in cashew production. As a result, most cashew plots were devastated by bush fires or pests and diseases built up with the unattended thickening of cashew tree canopies. Other reasons included adverse weather at the flowering stage and the negative response on the part of farmers to relatively low and stagnant cashewnut prices (see Figure 3.3) such that farmers paid less attention to the cashew crop in favor of other crops. This decline necessitated frequent closings of some of the processing plants resulting in redirection of shipments to open factories for processing.

The Cashewnut Authority of Tanzania (CATA), established in 1973 by a loan from the World Bank, is the authority responsible for the promotion of production, collection, processing, and marketing of cashewnuts in Tanzania.

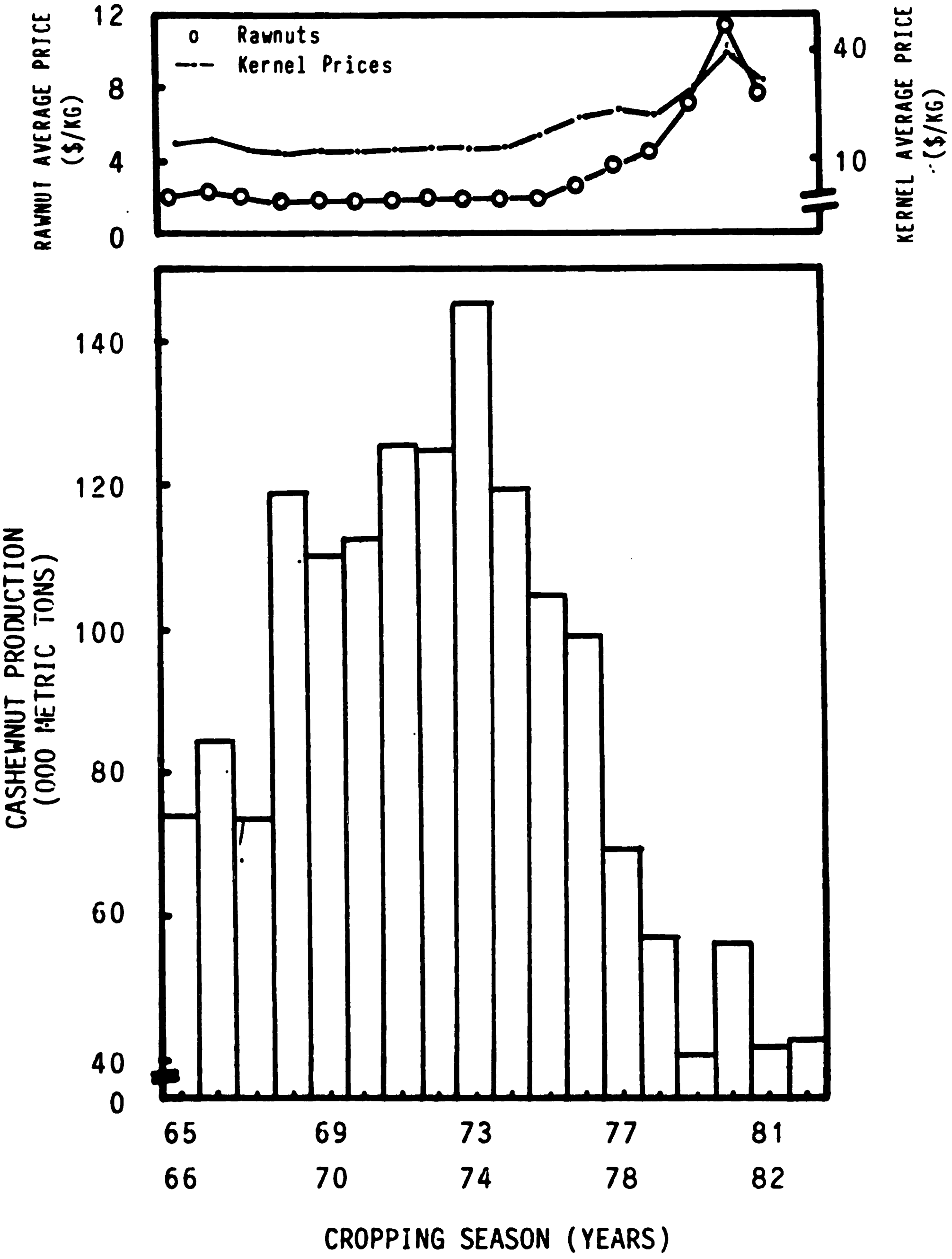


Figure 3.3. Cashewnut Production in Tanzania (1965-66 to 1982-83) and Cashew Prices.

Note: These are based on CATA figures which are different from FAO figures due to a different season reference.

Appendix A shows the CATA functional structure. At the village level, CATA advances money to the Village Planning Committee to buy the rawnuts on behalf of the Authority. A levy of 1¢ (about TAS 0.10) per kg purchased during the season is paid to the village at the end of the season. The Authority also makes arrangements for transporting the rawnuts to processing factories and later to port of export for the eventual sale of nuts and cashew products to buyers overseas.

CATA sells raw cashewnuts to India and China and cashew kernels—the main product of cashewnut processing—to the United States, Federal Republic of Germany, West Germany, Israel, Japan, and the Netherlands. Table 3.3 shows the cashew exports between 1975 and 1982. Table 3.4 provides the breakdown of cashew product exports between the same years.

Extension services and research are the responsibility of the Directorate of Crop Development and Production, which acts as a liaison with the Extension Services and Crop Research Organization of the Ministry of Agriculture. Naliendele Research Station (Mtwara) is the main research center and conducts research on cashews in order to improve the quality of cashewnut trees, increase their resistance to disease, and reduce vulnerability to adverse weather changes. The most important research in progress worth mentioning here is that related to development of mildew-resistant clones (of which, so far, two out of twelve clones

Table 3.3. Tanzania Cashewnut Export* (Rawnuts and Kernels): 1975-1982.

Year	RAWNUTS			KERNELS			
	Tonnes	Value $	Average Price $	Tonnes	Value $	$/kg	Average Rawnut Price $/kg
75-76	97328	27,385,250	1.97	3448	7,214,529	14.65	3.66
76-77	68006	24,251,470	2.59	5201	15,535,450	20.91	5.23
77-78	48400	25,432,540	3.68	2722	8,269,300	21.27	5.32
78-79	33019	20,781,670	4.41	3491	10,036,728	20.12	5.03
79-80	20863	16,021,800	6.97	3088	11,042,837	28.61	7.15
80-81	31539	40,092,019	11.48	5400	26,270,780	39.89	9.97
81-82	15329	12,459,130	7.72	5621	16,928,936	28.61	7.15

*Notice the general trend toward a possible complete processing of all nuts in Tanzania rather than selling unprocessed nuts (Table 3.4).

Table 3.4. Breakdown of Cashew Product Exports: Amounts and as a Percentage of Procurement*.

Year	Rawnuts		Kernels		Cashewnut Shell Liquid	
	Tonnes	%	Tonnes	%	Tonnes	%
76-77	68006	66.3	5201	24.6	2231	2.2
77-78	48400	66.8	2722	18.4	1167	1.6
78-79	33019	55.2	3491	28.6	1497	2.5
79-80	20863	50.3	3088	36.5	1324	3.2
80-81	31539	51.7	5400	43.4	2316	3.8
81-82	15329	34.6	5621	62.2	2410	5.4

*NOTE: Percent of total procurement is based on 20.4% and 8.75% recovery rates for kernels and cashewnut shell liquid, respectively.

have shown some prospects) and "chemical-application-manageable" canopies. The tall, profusely branching and sagging branched canopies, which are typical cashew trees in Tanzania, need considerable pruning to facilitate nut collection and are cumbersome during chemical applications for pest control.

In an effort to enhance smallholder production, CATA, under its first Five-Year Plan effective between the 1976-77 and 1981-82 seasons, proposed a rawnut production target of 180,000 tons per year by 1982. Table 3.5 shows the production projections and achievements under this plan. CATA was involved in the distribution of both seed and seedlings to farmers. In spite of the shortcomings in the first Five-Year Plan, a second Five-Year Plan (also ambitious) has targeted developing 25,000 hectares per year beginning in the 1983-84 season. Table 3.5 also gives long-term production increase estimates resulting from the first Plan, if it had been completely successful, and estimates of production increases based on achieved development.

It is apparent, however, that research and extension services as agents for the promotion of cashew production have suffered as a result of being under two institutions, CATA and the Ministry of Agriculture. Beginning with the 1984-85 season, a re-establishment of Cooperative Unions will take place; CATA will act only as a processing and marketing board. Crop development and production of cashewnuts will then fall wholly under the Ministry of

Table 3.5. First Five-Year Plan (1976-77 to 1981-82) Estimates of Increases in Rawnut Production:* Actual and Projected.

Year Established	Ha to Be Established (Achieved)	ESTIMATED YEARLY AMOUNTS IN KILOGRAMS (Actual)													
		78-79	79-80	80-81	81-82	82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	90-91	91-02
76-77	8000 (8065)	- -	300 (302)	1400 (1411)	2200 (2218)	3100 (3125)	3600 (3629)	4200 (4234)	4800 (4839)	5300 (5343)	5300 (5343)	5300 (5343)	5300 (5343)	5300 (5343)	5300 (5343)
77-78	22000 (16466)	- -	- -	800 (598)	3800 (2844)	6200 (4640)	8500 (6362)	10000 (7484)	11600 (8682)	13100 (9805)	14600 (10927)	14600 (10927)	14600 (10927)	14600 (10927)	14600 (10927)
78-79	30000 (7348)	- -	- -	- -	1000 (245)	5300 (1298)	9400 (2057)	11200 (2743)	13700 (3356)	15800 (3870)	17900 (4384)	20000 (4898)	20000 (4898)	20000 (4898)	20000 (4898)
79-80	30000 (8388)	- -	- -	- -	- -	1000 (280)	5300 (1482)	8400 (2348)	11200 (3131)	13700 (3830)	15800 (4418)	17900 (5005)	20000 (5592)	20000 (5592)	20000 (5592)
80-81	30000 (4389)	- -	- -	- -	- -	- -	1000 (146)	5300 (775)	8400 (1229)	11200 (1638)	13700 (2004)	15800 (2311)	17900 (2618)	20000 (2926)	20000 (2926)
81-82	30000 (7768)	- -	- -	- -	- -	- -	- -	1000 (259)	5300 (1372)	8400 (2175)	11200 (2900)	13700 (3547)	15800 (4091)	17900 (4635)	20000 (5178)
TOTAL	150000 (52424)	- -	300 (302)	2200 (2009)	7000 (5307)	15600 (9343)	26800 (13676)	40100 (17843)	55000 (22609)	67500 (26661)	78500 (29976)	87300 (32031)	93600 (33469)	97800 (34321)	99900 (34864)

*Production target of 180,000 tons/year is based on 1967-77 production of 100,000 tons/year.

Source: CATA files.

Agriculture. The current arrangement, in which CATA purchases rawnuts from individual villages, will cease, and the Cooperative Unions will be responsible for the purchase and transportation of rawnuts from member villages to production centers. CATA will be responsible for the purchase and transportation of rawnuts from the production centers to the processing plants.

3.3.2. Tanzania Cashew Industry: Production Levels, Costs, Plant Capacities, and Distances

Data on individual villages' rawnut production levels were available. To a large extent, location of production centers was determined by existing road networks and district boundaries. It was found realistic, on the grounds of justifying a reasonable number of truck loads and maximum distances to the production center, to cluster villages into groups, each group being served by one production center (a 120-mile radius was assumed). Appendix B gives the mileage chart for distances between production centers. Table 3.6 shows the capacities of existing cashewnut processing plants and their code numbers as used in this study.

As a result of the increase in fuel prices, transportation costs per kilometer have varied between 14¢ (TAS 1.80 per tonne per mile) per tonne in 1977 to 26¢ per tonne (TAS 3.50 per tonne per mile) in 1982 and were approximately the same for different parts of the cashewnut production region.

Table 3.6. Average Annual Fixed Costs and Operating Costs and Amounts Processed for Existing Processing Plants+.

Code Number	Plant Site	Rated Capacity (000 tonnes)	Fixed Charge* (F_i) ($000)	Amount Processed (tonnes)	Variable Cost ($000)
5	Lindi	5	280	2226	1045.0
6	Mtama	5	312	3348	1360.2
7	Nachingwea	5	221	277	180.9
4	Kilwa	5	250	—	—
12	Mtwara	8	375	—	—
11	Likombe	10	390	—	—
8	Masasi	10	390	1800	897.9
9	Newala I	10	390	4320	1680.0
10	Newala II	10	390	7680	2160.0
13	Tunduru	10	430**	—	—
3	Kibaha	10	430	6055	1985.9
1	Tanita I	12	650	9120	2240.0
2	Tanita II	12	680	10400	2300.0

+Based on 1980-81 CATA figures.

*Includes direct labor, fixed factory overhead, and administrative expenses.

*CATA estimates (factory under construction, to be commissioned in 1984-85).

According to the above trends, it is reasonable to assume that transportation costs will double every five years.

Factory production costs, on the other hand, have varied among factories. Appendix C gives an example of a summary of production costs for some of the factories. Typical items included in the packing materials, variable factory overheads, and typical depreciation rates on capital items are given in Appendix D. Due to differences in cashew quality resulting from, among others, variable recovery rates from different factories and below-capacity operation of factories, the variable costs in relation to factory throughputs are difficult to visualize. Hence, Figure 3.4 shows the combined concave cost function depicting the variable cost trend with increasing factory throughputs derived from cost figures in Table 3.6. Table 3.7 shows examples of factory recovery rates for the kernels and CNSL, the main products of cashew processing, for two representative factories. Appendix E gives typical factory production figures showing kernel grade outputs for one year (1981-82) and regional range of kernel grade outputs that may be expected from a factory.

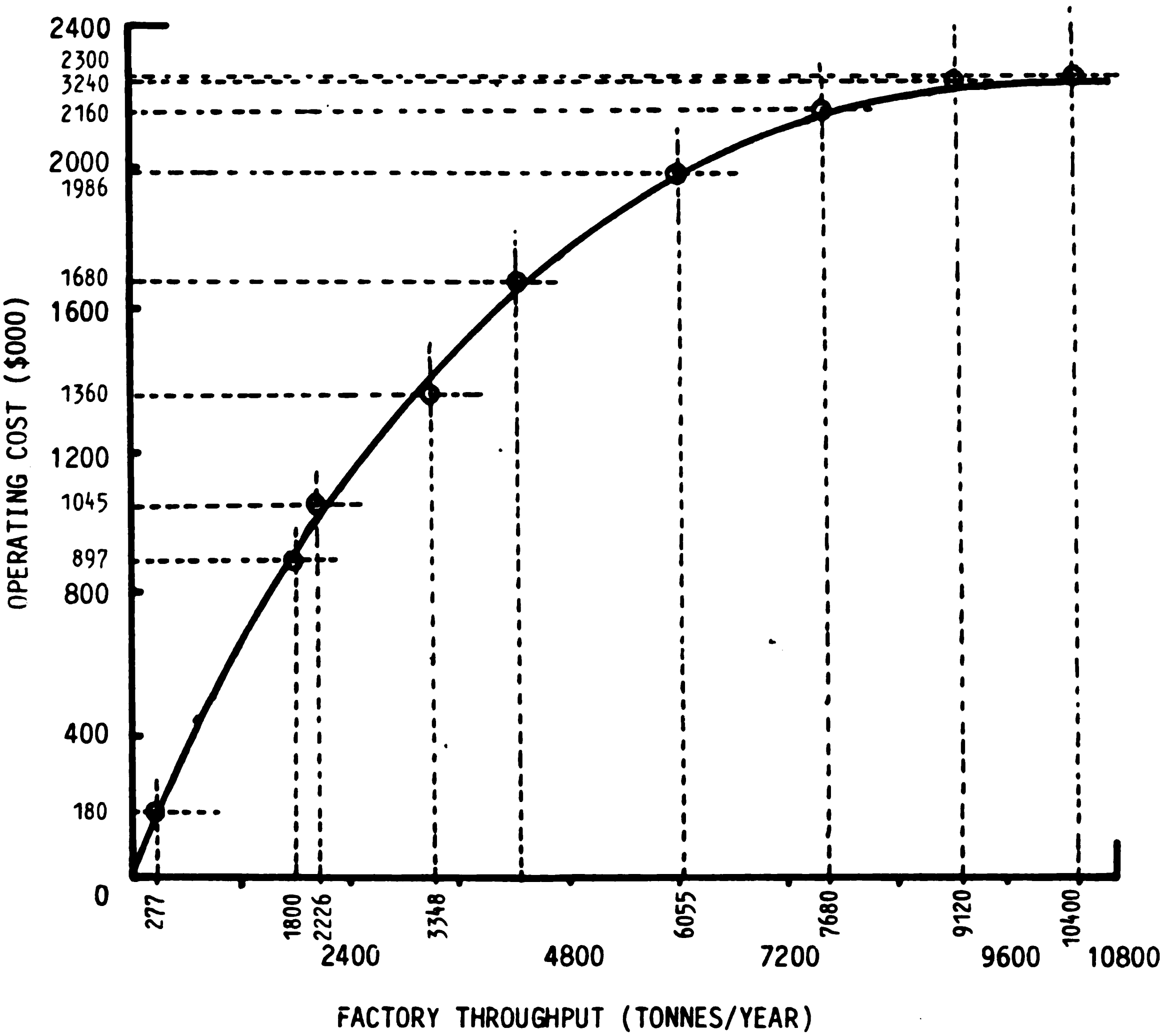


Figure 3.4. Cashewnut Processing Plant Operating Costs (Combined-Concave Cost Function)

Note: Fixed costs excluded.

Table 3.7. Recovery Rates for Lindi and Kibaha Cashew Factories: 1980-81 and 1981-82.

Month	1980-1981				1981-1982			
	Lindi		Kibaha		Lindi		Kibaha	
	% Kernel	% CNSL	% Kernel	% CNSL	% Kernel	% CNSL	% Kernel	% CNSL
October	14.6	7.0	—	—	—	—	—	—
November	17.5	7.0	34.1	11.8	—	—	—	—
December	19.5	7.0	22.3	11.8	—	—	—	—
January	24.0	7.0	22.4	12.0	—	—	—	—
February	18.6	7.0	21.0	9.1	19.8	12.1	—	—
March	10.0	7.0	20.0	10.0	24.9	7.4	—	—
April	19.9	7.0	16.4	11.1	21.0	7.4	19.2	11.2
May	21.4	7.0	20.9	7.7	19.4	7.2	22.5	12.2
June	—	—	—	—	18.2	7.1	21.4	10.5
July	—	—	—	—	18.9	7.0	20.5	9.9
August	—	—	—	—	19.0	7.0	19.9	9.5
September	19.1	6.6	—	—	21.7	7.0	25.2	10.9
Factory Average	18.3	7.0	22.4	10.5	20.4	7.8	21.5	10.7
Std Dev	±4.01	±0.13	±5.52	±1.64	±2.16	±1.76	±2.17	±0.97
Overall:	Average Kernel Recovery Rate: 20.4% (Std Dev ±3.92) Average CNSL* Recovery Rate: 8.75% (Std Dev ±2.06)							

*Density of CNSL is approximately 0.89 kg/liter.

CHAPTER 4

CASHEW INDUSTRY LOCATIONAL STUDY MODEL: MODEL DATA INPUTS ANALYSIS, ALGORITHM, AND ASSUMPTIONS

4.1. Input Data Analysis

4.1.1. Estimating Production Levels ("Demand Pattern")

Estimates of increases in production center production levels (total and zonal) creating a processing demand based on the Five-Year Plan figures seem very optimistic, as may be calculated by adding estimated yearly increases (Table 3.5) to the preceding actual production figures (Table 3.2). For example:

Actual:	Total production, 1982-83 season (Table 3.2):	32,743 tonnes
Calculated:	Actual preceding year (1981-82) production (Table 3.2):	44,326 tonnes
	Estimated yearly increase (Table 3.5):	9,343 tonnes
	Estimated Total (optimistic)	53,669 tonnes

This overestimation resulted from the overestimation of cashew yields per tree as well as underestimating the cashew yield decline by older trees. Figure 4.1 shows the relation between production year (beginning in the 1982-83 season) to the production level in the next five years, i.e., a production level prediction curve. The assumption made in the prediction equation derivation is that increases

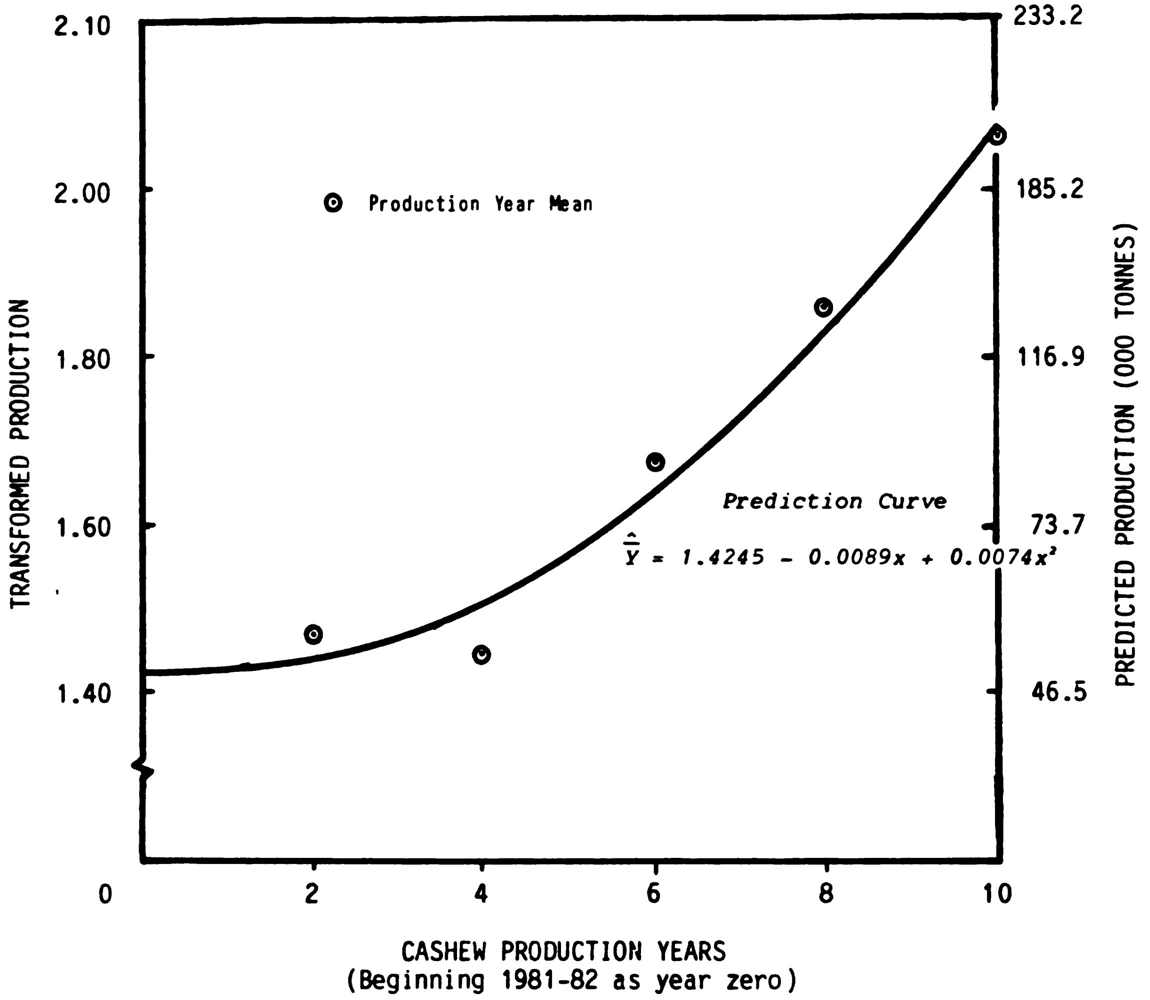


Figure 4.1. Relationship Between Subregions' Annual Cashewnut Production Level (Transformed and Real Data) and Production Year for a Ten-Year Period.

in production levels will follow a similar pattern as the decline between 1973-74 and 1981-82 seasons. The prediction equation is derived by use of orthogonal polynomials. Appendix F gives the details of the derivation procedures. Figure 4.1 also shows the transformed production year, production level means. Table 4.1 gives the production center production levels derived from the use of the prediction equation.

4.1.2. Estimating the Cost Functions

Three costs are considered in this study: an annual fixed charge, processing plant operating cost coefficient, and unit shipment cost. The annual fixed charge includes both investment costs and construction of facilities and other fixed indirect charges (administrative expenses, direct labor, and fixed factory overheads) which are incurred when the facility is or was constructed, regardless of its output. Figures listed in Table 3.6 form the basis of fixed charge estimates for each existing factory. The operating cost coefficient estimates are based on the combined concave cost function (Figure 3.4). Combined individual fixed cost and operating cost functions shown in Figures 4.2 to 4.10 are used to determine the cost coefficients. A "pseudo" tangent-chord approximation, with one and also two linear segments in the pseudo, piecewise-linear approximation, are shown in Figures 4.2 to 4.10 as two examples of finding approximations to the fixed costs (Fi*)

Table 4.1. Production Center Production Level Estimates (Metric Tons) by Subregion: 1982-83 to 1991-92.+

Subregions		%*	Year of Production (000 Tonnes)									
#	Name		82-83	83-84	84-85	85-86	86-87	87-88	88-89	89-90	90-91	91-92
1	Mtwara	7.03	1,767	3,448	3,556	3,793	4,187	4,782	5,651	6,909	8,740	11,440
2	Newala	24.20	9,506	11,870	12,239	13,058	14,413	16,461	19,452	23,783	30,086	39,379
3	Masasi	16.41	4,323	8,049	8,300	8,854	9,774	11,162	13,190	16,127	20,401	26,703
4	Lindi	5.56	1,174	2,727	2,812	3.000	3,312	3,782	4,469	5,464	6,913	9,048
5	Mtama	11.37	3,371	5,577	5,451	6,135	6,772	7,734	9,139	11,174	14,136	18,502
6	Nachingwea	4.20	812	2,060	2,124	2,266	2,502	2,857	3,376	4,128	5,222	6,835
7	Liwale	2.00	935	981	1,012	1,079	1,191	1,361	1,608	1,966	2,487	3,255
8	Kilwa	3.38	567	1,658	1,710	1,824	2,013	2,299	2,717	3,322	4,202	5,500
9	Tunduru	5.41	2,092	2,654	2,736	2,919	3,222	3,680	4,349	5,317	6,726	8,804
10	Songea	0.21	55	103	106	113	125	143	169	207	261	342
11	Kisarawe	10.66	4,067	5,229	5,39±	5,752	6,349	7,251	8,569	10,476	13,253	17,346
12	Kibaha	1.16	686	569	587	626	691	789	932	1,140	1,442	1,888
13	Bagamoyo	0.96	469	471	486	518	572	653	772	944	1,194	1,562
14	Utete	2.59	1,077	1,270	1,310	1,398	1,543	1,762	2,082	2,545	3,220	4,215
15	Mafia	0.33	293	162	167	178	197	225	265	324	411	537
16	D'salaam	1.57	500	770	794	847	935	1,068	1,262	1,543	1,951	2,555
17	Tanga	2.72	515	1,334	1,376	1,468	1,620	1,850	2,186	2,673	3,382	4,426
18	Mbeya	0.03	139	15	15	16	18	21	24	30	38	49
19	Morogoro	0.20	125	98	101	108	119	136	161	197	249	326
Approximate Total:		100.	32,473	49,045	50,573	53,952	59,555	68,016	80,373	98,269	124,315	162,712
Predicted Total:			32,473	49,051	50,576	53,957	59,559	68,022	80,380	98,276	124,322	162,722

*Based on 1980-81 CATA figures.

+Based on prediction equation: $\hat{Y} = 1.4245 - 0.0089x + 0.0074x^2$

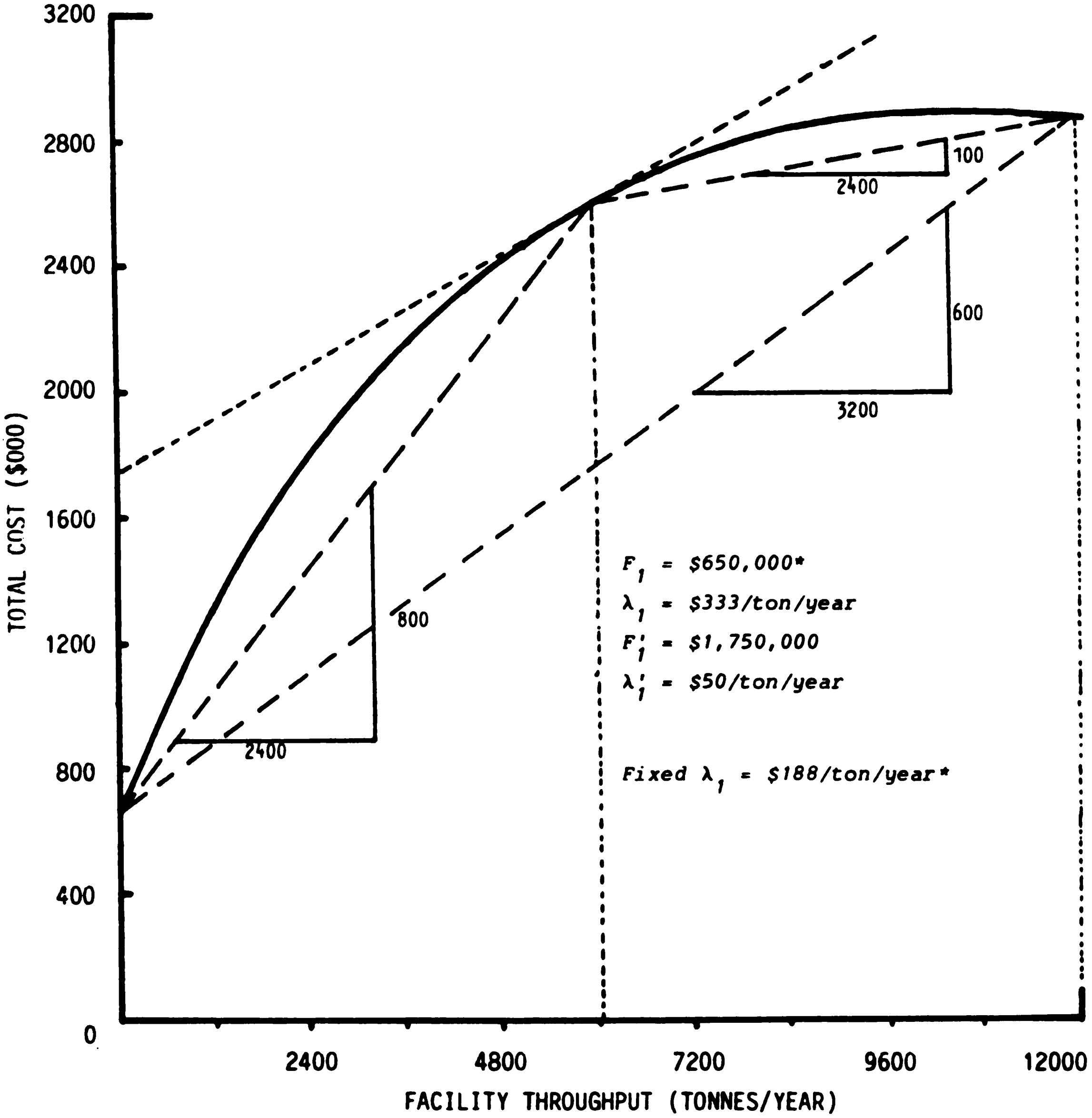


Figure 4.2. Tanita I: Cashewnut Processing Total Cost Curve: Cost Coefficients.

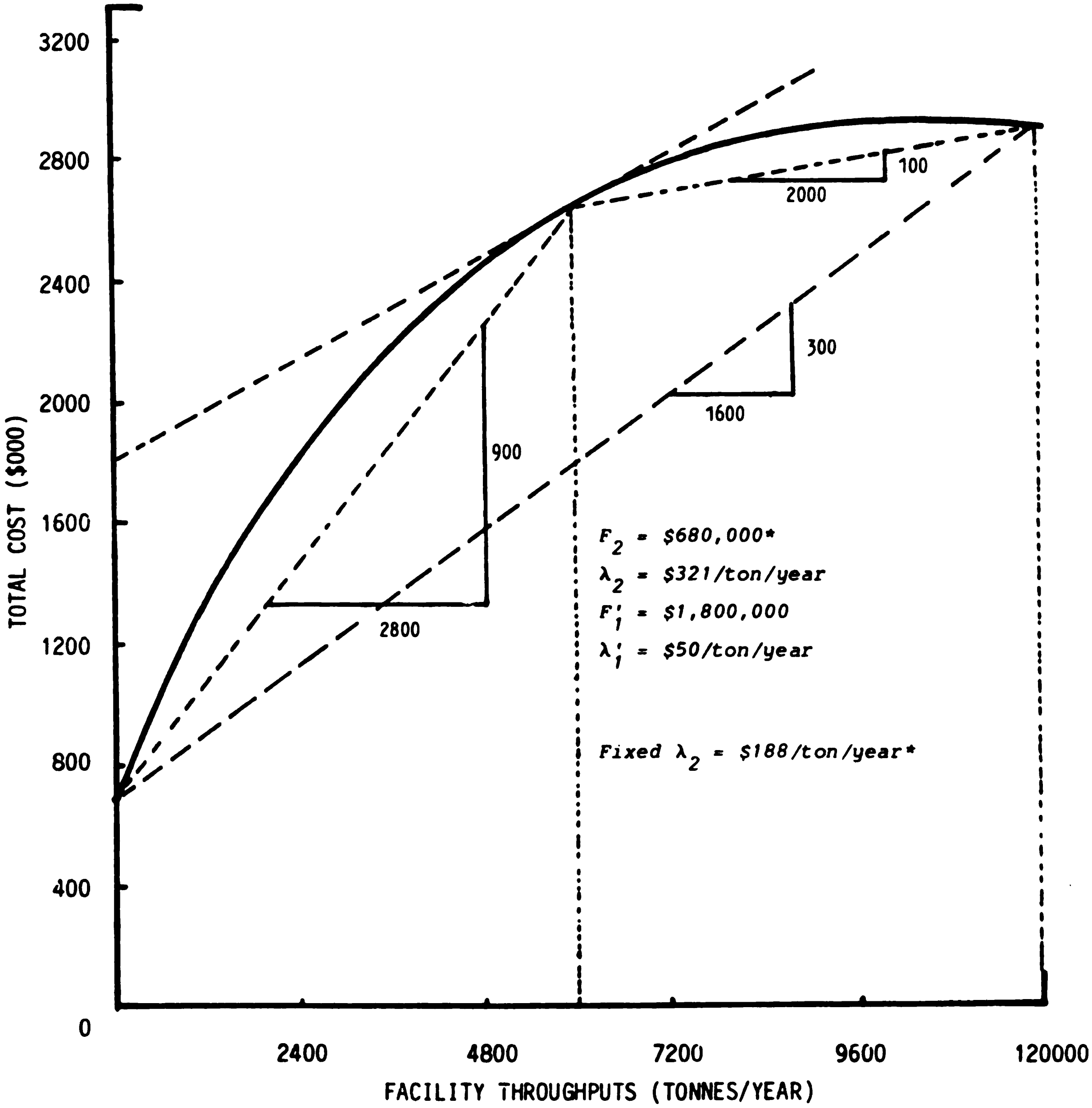


Figure 4.3. Tanita II: Cashewnut Processing Total Cost Curve.

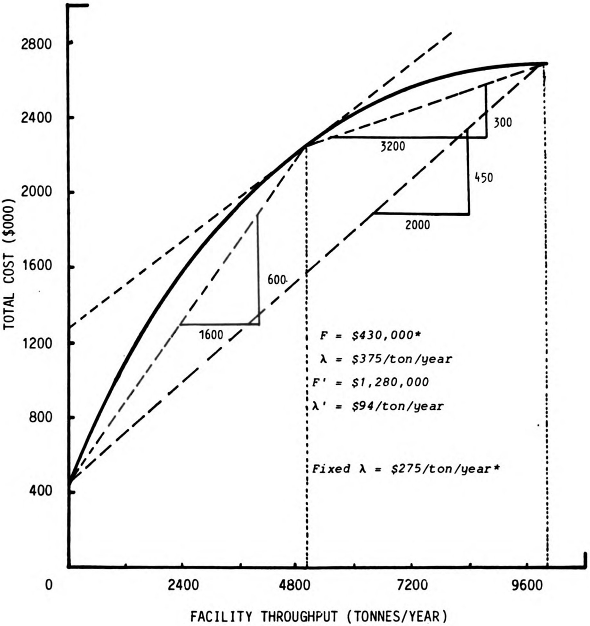


Figure 4.4. Kibaha and Tunduru: Cashewnut Processing Total Cost Curve.

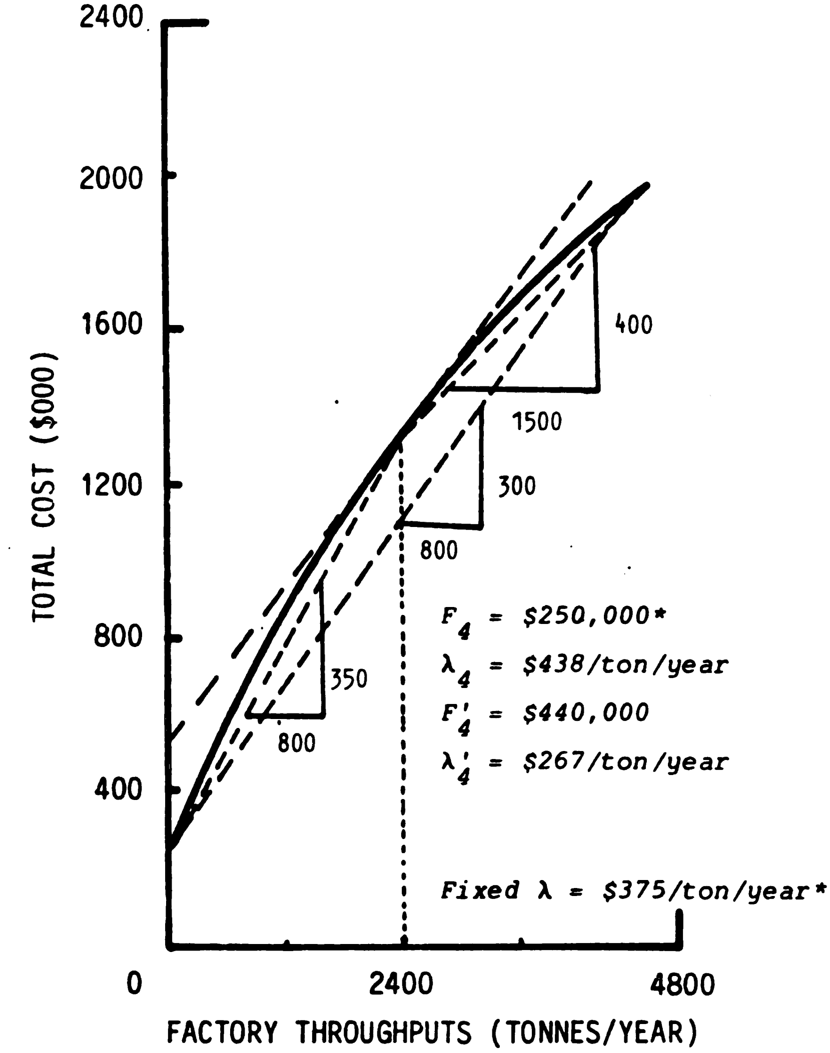


Figure 4.5. Kilwa: Cashewnut Processing Total Cost Curve: Cost Coefficients.

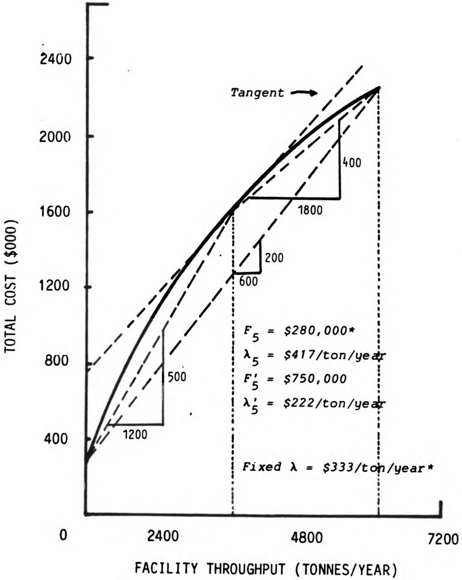


Figure 4.6. Lindi: Cashewnut Processing Total Cost Curve.

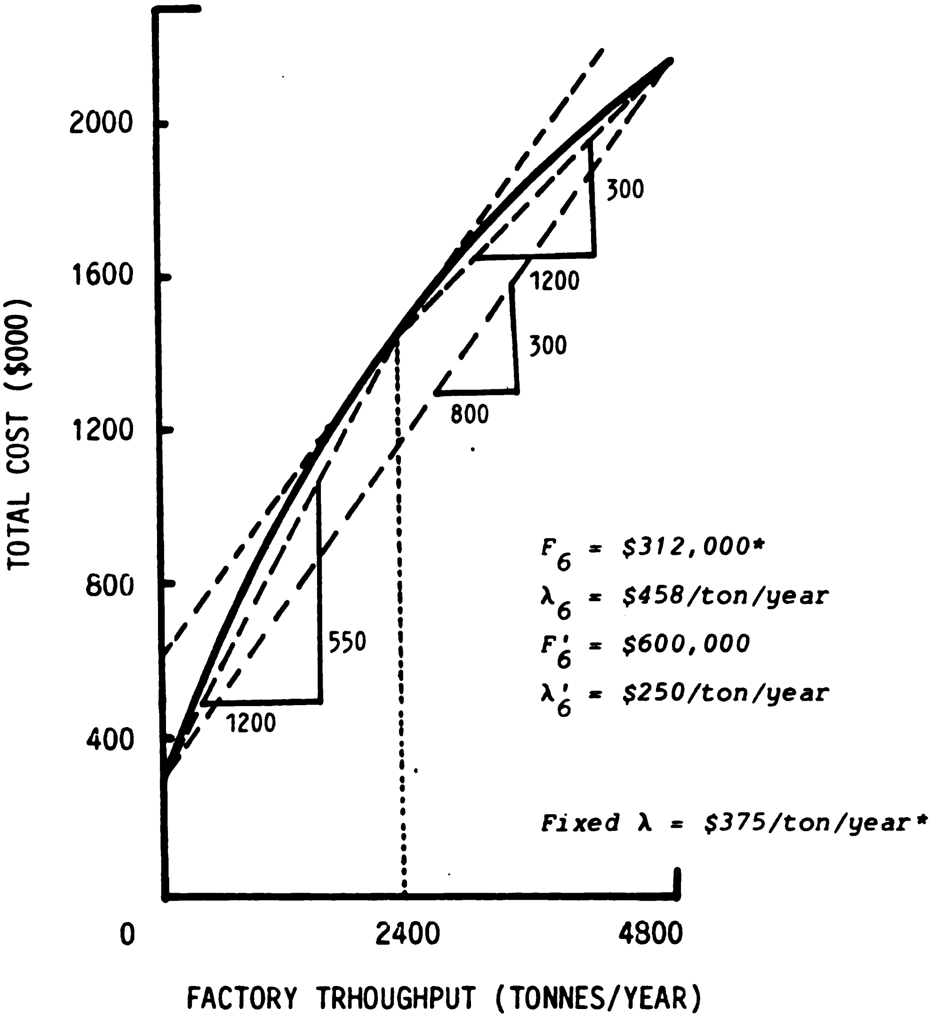


Figure 4.7. Mtama: Cashewnut Processing Total Cost Curve.

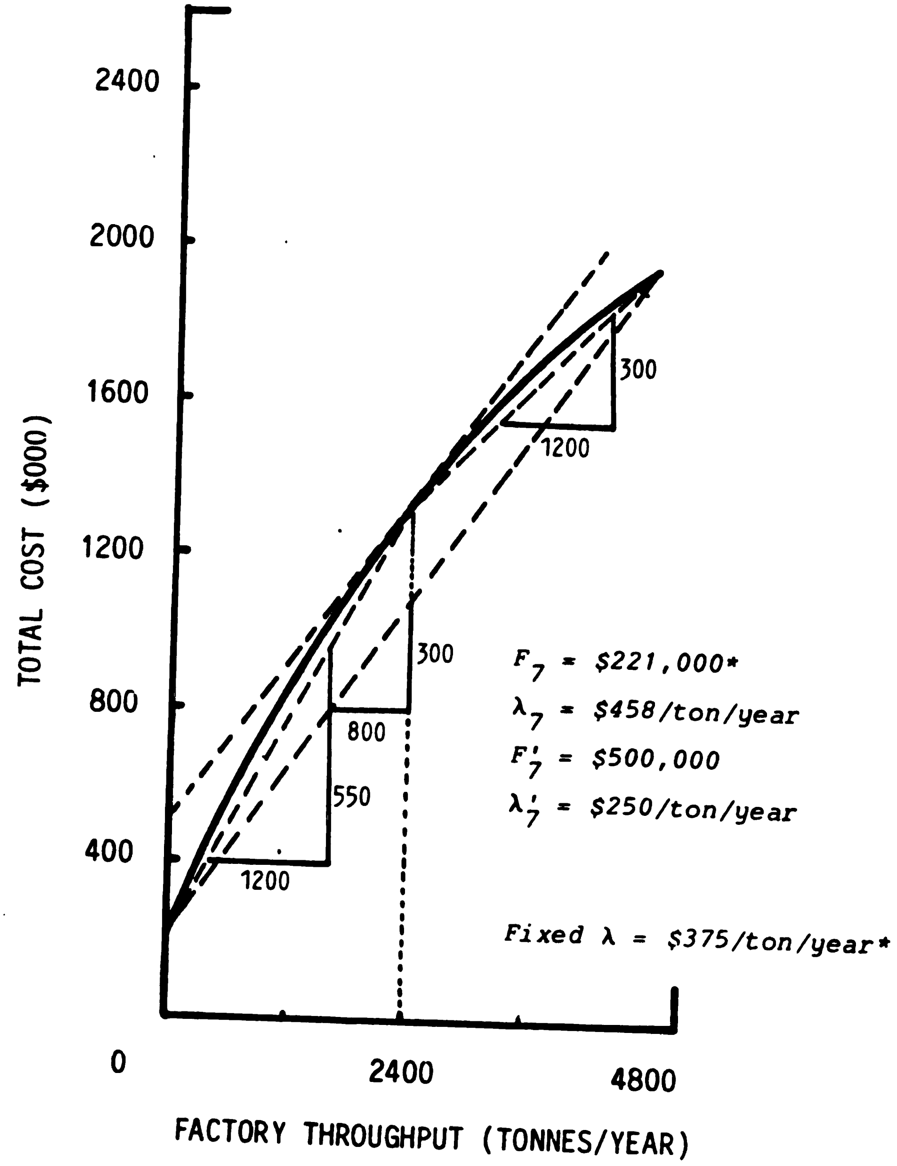


Figure 4.8. Nachingwea: Cashewnut Processing Total Cost Curve.

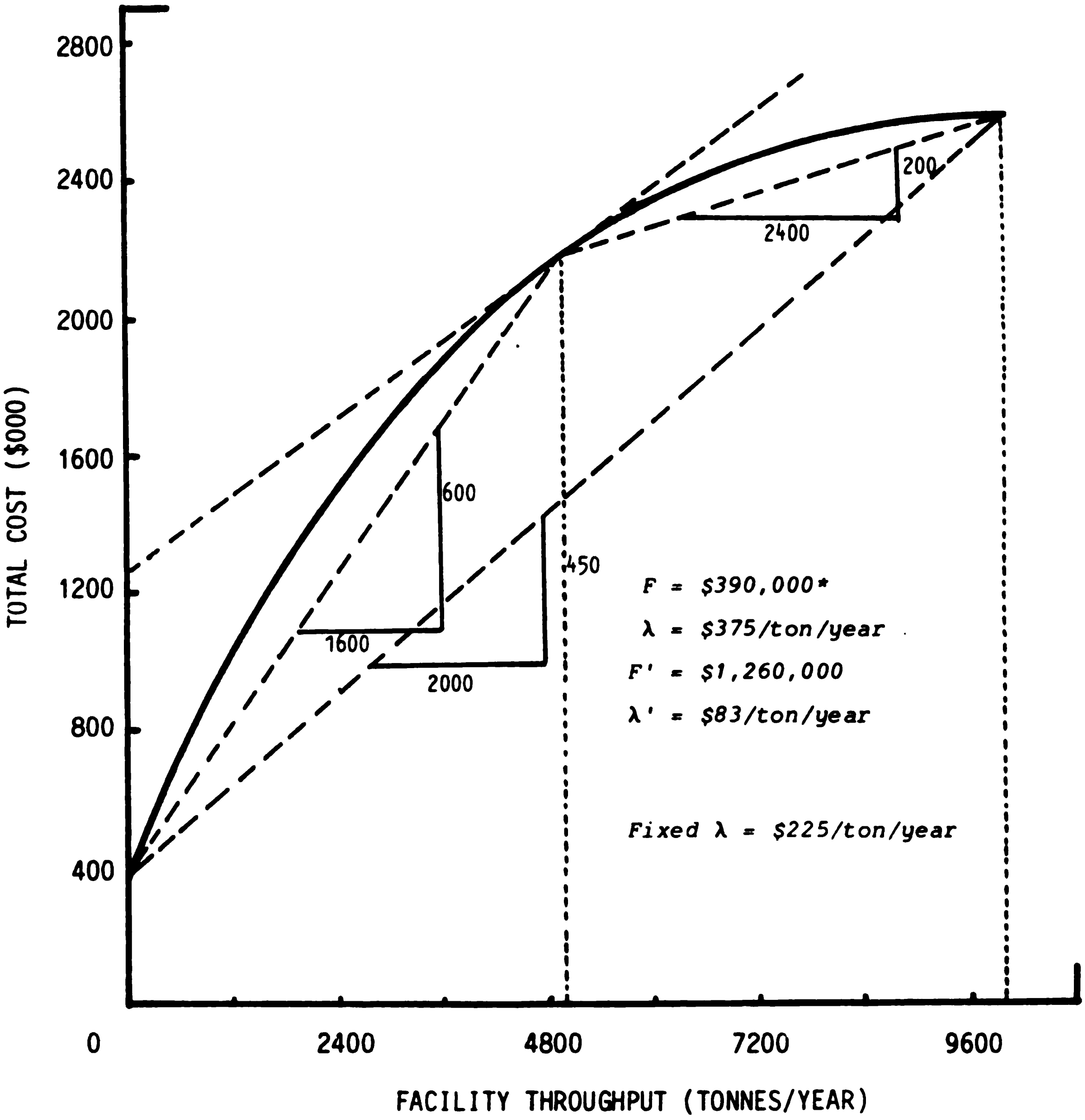


Figure 4.9. Likombe, Masasi, Newala I and Newala II: Cashewnut Processing Total Cost Curve.

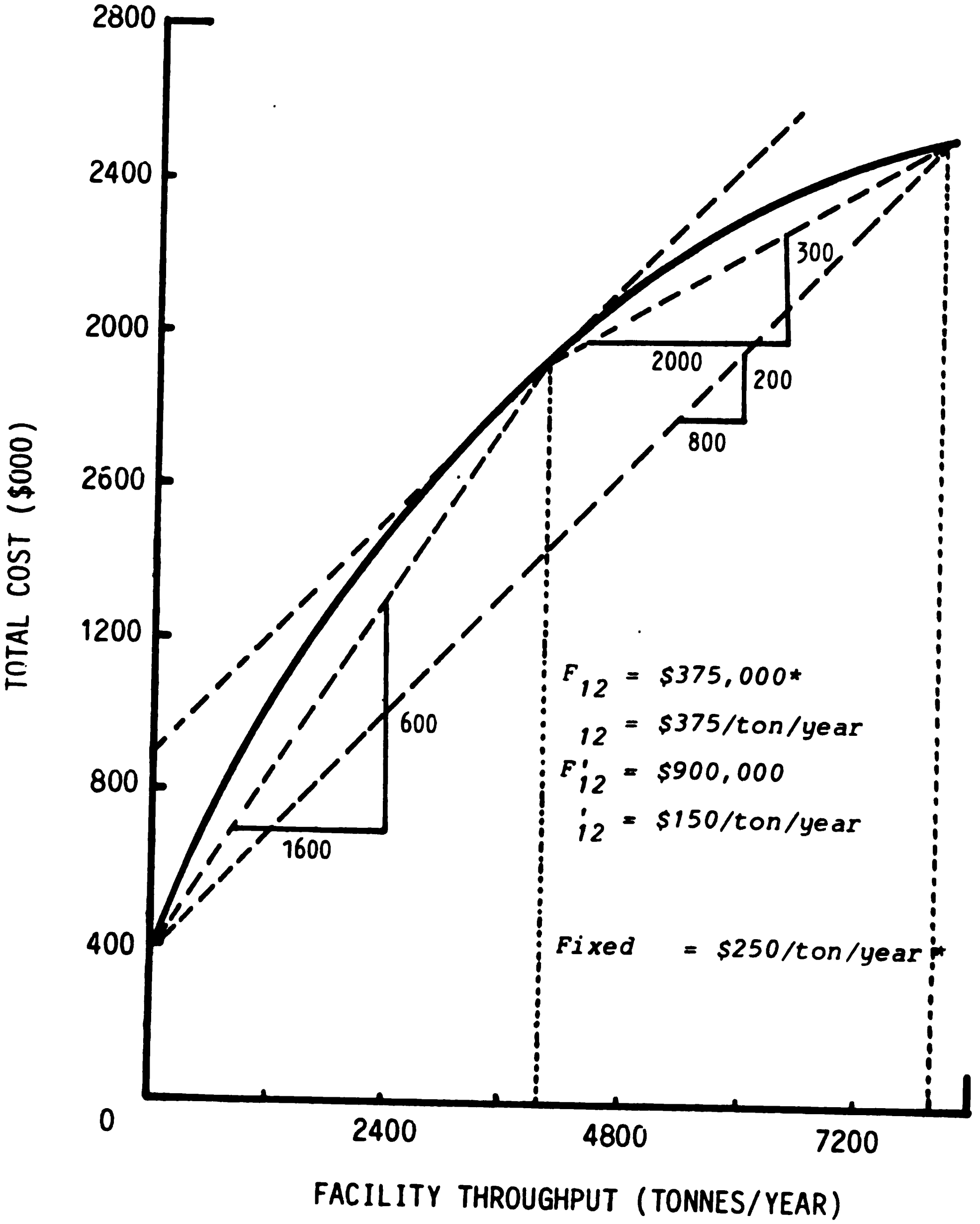


Figure 4.10. Mtwara: Cashewnut Processing Total Cost Curve.

and operating cost coefficients (λ_i^*) using piecewise linear approximation methods. The word "pseudo" is used in this case because the fixed charge is found from the extrapolation of the tangent at the minimum capacity in that linear segment rather than the extrapolation of the chord itself, which usually tends to overestimate fixed costs. This approximation of the fixed cost estimates is a compromise between piecewise-linear and the tangent-chord approximation methods (see Figures 2.12 and 2.14 for detail).

In this study, however, due to financial reasons, operating costs are based upon a fixed charge cost rather than two segments in a piecewise linear approximation and are included in the unit shipment cost data inputs. This means that each unit of cashewnut sent from a production center to a processing plant brings with it both shipment and operating charges to the assigned processing plant site. Conceptually, processing plants in the feasible set (free facilities) are competing to drop their production centers in order to avoid incurring their fixed costs and shipment costs. On the other hand, processing plants in the feasible set earmarked open are competing to serve production centers in an effort to reduce the variable system's cost.

Tables 4.2 and 4.3 give the cost per tonne per year matrix, C_{ij}, where, for the first stage (Production Center - Processing Plants):

Table 4.2. Cost Per Tonne-Year Matrix* for Fixed Charge Setting.

PLANT-FACILITY (I)			PRODUCTION CENTER (J) ($)																			
#	CAP (000)	FXD (000)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	12,000	650,000	308.0	375.6	339.7	260.2	298.1	329.9	398.0	160.9	439.6	469.1	20.5	25.1	40.2	100.0	60.5	12.7	216.5	432.8	100.0	Tanita I
2	12,000	680,000	302.5	368.9	333.0	253.9	291.4	324.7	391.2	154.1	432.8	468.7	27.2	31.9	47.0	93.8	60.5	12.7	223.3	439.6	106.8	Tanita II
3	10,000	430,000	333.0	400.6	364.7	285.7	323.1	256.4	423.0	185.9	464.6	437.0	45.5	22.1	65.2	125.0	91.7	25.2	191.6	407.9	75.1	Kibaha
4	5,000	250,000	154.3	215.1	179.3	100.2	127.7	170.9	237.5	51.3	279.1	403.9	181.3	186.0	201.1	61.2	115.3	154.3	377.4	638.9	245.1	Kilwa
5	5,000	280,000	54.4	115.3	79.4	28.9	37.8	71.1	137.6	100.2	179.2	304.0	281.1	285.8	300.9	161.0	215.1	254.1	477.2	539.1	353.9	Kindi
6	5,000	312,000	66.9	42.0	42.0	37.8	32.1	33.7	100.2	137.7	141.8	266.6	318.6	323.3	338.4	198.5	485.9	291.6	514.7	501.7	391.4	Mtama
7	5,000	221,000	100.2	60.7	24.8	71.1	33.7	18.1	66.9	170.9	124.7	249.5	351.9	356.6	371.7	231.8	185.9	324.9	547.9	484.0	424.7	Nachingwea
8	10,000	390,000	108.4	36.1	27.8	79.3	41.8	31.4	91.2	179.1	100.1	224.9	360.1	364.7	379.8	239.9	294.0	333.0	556.1	459.9	432.9	Masasi
9	10,000	390,000	73.0	21.0	36.1	115.1	41.8	60.5	127.1	215.0	135.9	260.7	395.4	400.6	415.7	275.8	329.9	368.9	592.0	495.3	468.7	Newala I
10	10,000	390,000	75.0	21.0	36.1	115.1	41.8	60.5	127.1	215.0	135.9	260.7	395.4	400.6	415.7	275.8	329.9	368.9	592.0	495.3	468.7	Newala II
11	10,000	390,000	25.2	73.0	108.3	54.3	66.8	100.1	166.6	154.1	208.2	333.0	328.3	333.0	348.1	215.0	269.1	301.8	524.4	568.1	401.7	Likombe
12	8,000	375,000	25.2	73.1	108.4	54.3	66.8	100.1	166.7	145.2	208.3	333.1	328.4	333.1	348.1	215.0	269.1	301.9	542.4	568.1	401.7	Mtwara
13	10,000	430,000	208.1	135.9	100.1	179.1	125.0	124.5	226.9	278.9	26.2	125.0	459.9	464.6	479.7	339.8	393.9	432.9	655.9	360.1	532.7	Tunduru
Demand Level			PRODUCTION CENTER LEVELS — Refer to Table 4.1																			
			Mtwara	Newala	Masasi	Lindi	Mtama	Nachingwea	Liwale	Kilwa	Tunduru	Songea	Kisarawe	Kibaha	Bagamoyo	Utete	Mafia	Dar es salaam	Tanga	Mbeya	Morogoro	

*Includes plant capacities and fixed costs. Matrix for 26¢/km-tonne-year (1982-83 t0 1986-87).

Table 4.3. Cost Per Tonne-Year Matrix* for Fixed Charge Setting.

PLANT-FACILITY (I)			PRODUCTION CENTER (J) ($)																			
#	CAP (000)	FXD (000)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	12	650	615.9	751.1	679.3	520.2	596.1	659.5	795.8	321.5	879.0	923.7	40.7	50.1	80.3	199.9	133.3	25.1	432.8	865.5	199.9	Tanita I
2	12	680	602.4	737.5	665.8	507.7	582.6	649.1	782.3	308.0	865.5	937.2	54.3	63.6	93.8	187.4	120.8	25.1	446.3	879.0	213.4	Tanita II
3	10	430	665.8	801.0	729.3	571.2	646.1	712.6	834.7	371.5	928.9	873.8	90.7	43.9	130.2	249.8	183.3	50.1	382.9	815.6	150.0	Kibaha
4	5	250	308.2	429.9	358.1	200.1	274.9	341.5	474.6	102.3	557.8	807.4	362.3	371.7	401.8	122.1	230.2	308.2	754.4	1277.5	507.9	Kilwa
5	5	280	108.5	230.2	158.4	57.5	75.2	141.8	274.9	200.0	358.1	607.7	561.9	571.3	601.5	321.7	429.9	507.9	954.0	1077.8	707.5	Lindi
6	5	312	133.5	83.6	83.6	75.3	63.8	66.9	200.1	274.9	283.3	532.9	636.9	646.2	676.4	396.6	504.8	582.8	1028.9	1002.9	782.5	Mtama
7	5	221	200.1	121.0	49.3	141.8	66.9	35.7	133.5	341.5	248.9	498.5	703.4	712.8	742.9	463.2	571.3	649.3	1095.5	967.6	849.0	Nachingwea
8	10	390	216.5	72.0	55.3	158.3	83.4	62.6	182.2	358.0	199.9	449.5	719.9	729.3	759.4	479.7	587.8	665.8	1112.0	919.6	865.5	Masasi
9	10	390	145.8	41.8	72.0	230.1	83.4	120.9	254.0	429.7	271.7	521.3	790.6	801.0	831.2	551.4	659.6	737.6	1183.7	990.3	937.3	Newala I
10	10	390	145.8	41.8	72.0	230.1	83.4	120.9	254.0	419.7	271.7	521.3	790.6	801.0	831.2	551.4	659.6	737.6	1183.7	990.3	957.3	Newala II
11	10	390	50.1	145.8	216.5	108.4	133.3	199.9	333.0	308.1	416.2	665.8	656.5	665.8	696.0	429.7	537.9	603.3	1048.5	1135.9	803.1	Likombe
12	8	375	50.2	145.9	216.6	108.4	133.4	199.9	333.1	308.1	416.3	665.9	656.5	665.9	696.0	429.8	537.9	603.5	1048.6	1135.9	803.1	Mtwara
13	10	430	416.2	271.7	199.9	358.0	249.8	248.8	453.7	557.7	52.2	249.8	919.6	928.9	959.1	679.3	787.5	865.5	1311.7	719.9	1065.2	Tunduru
14	10	430	1048.5	1183.7	1112.0	953.9	1028.8	1095.3	1232.0	754.2	1311.7	1369.9	473.4	382.9	512.9	646.1	579.5	432.9	125.0	1311.7	399.6	Tanga
15	10	430	429.7	551.4	479.7	321.6	396.5	463.0	596.1	121.9	679.3	1123.4	240.5	249.8	280.0	80.3	108.4	199.9	646.1	1065.2	399.6	Utete
			Mtwara	Newala	Masasi	Lindi	Mtama	Nachingwea	Liwale	Kilwa	Tunduru	Songea	Kisarawe	Kibaha	Bagamoyo	Utete	Mafia	Dar es salaam	Tanga	Mbeya	Morogoro	

*Includes plant capacities and fixed costs. Matrix for 52¢/km-tonne-year (1987-88 to 1991-92).

$$C(I,J) = \left(\begin{matrix}\text{Return Journey Distance}\\ \text{Between Facilities}\end{matrix}\right)\left(\begin{matrix}\text{Unit Shipment}\\ \text{Costs}\end{matrix}\right) + \text{Unit Operating Costs Coefficient} \qquad [4.1]$$

and for the second stage (Processing Plant - Export Depot):

$$C(I,J) = \left(\begin{matrix}\text{Return Journey Distance}\\ \text{Between Facilities}\end{matrix}\right) \times \left(\begin{matrix}\text{Unit Shipment}\\ \text{Costs}\end{matrix}\right) \qquad [4.2]$$

Currently, only Dar es salaam and Tanga are designated ports of export. A solution of two transportation problems is preferred to the solution of a transshipment problem, mainly because the procedure allows for decentralization of facilities regionalwise. The export amount (%) for each cashew product ($\hat{Y}$) is predicted using prediction equations based on figures in Table 3.4 (derivation summary is given in Appendix J):

$$\text{Rawnuts:} \quad \hat{Y} = 75.01 - 5.96x \qquad r^2 = .89 \qquad [4.3]$$

$$\text{Kernels:} \quad \hat{Y} = 8.53 + 7.74x \qquad r^2 = .85 \qquad [4.4]$$

$$\text{CNSL:} \quad \hat{Y} = 0.78 + 0.67x \qquad r^2 = .85 \qquad [4.5]$$

where x is the production year ($x=1,2,...,10$).

But since export depots can be assumed to have no capacity restrictions, shipment of all the output of each source to that one destination with the least associated marginal cost results in the least-cost allocation (Ademosun and Noble, 1982). It follows, therefore, that each processing unit will be allocated to the nearest export depot.

This excludes the necessity for solving the second transshipment problem.

Where data are not complete and for new factories to be established, average estimates for existing factories are used to estimate costs of similar capacity facilities.

4.1.3. Facility Capacities

For the establishment of new factories, available figures for the modern 10,000-tonne capacity factory (such as Kibaha or Tunduru) are used. Apparently, the 10,000-tonne capacity factories are preferred by CATA authorities, and, as the operating cost function curve indicates, it is with good reason. For established factories, capacities in Table 3.6 are used.

4.2. The Algorithm

The algorithm used to solve the cashew industry facility location-allocation problem was constructed according to the flow charts in Figures 4.11 and 4.12. A FORTRAN interface was used to link the linear, interactive, and discrete optimizer (LINDO) package. The major features of LINDO (Schrage, 1982) are:

(a) Flexibility: Over forty commands for data input, editing, optimization, display, file handling, and sensitivity analysis.

(b) Power: Depends upon the size of the computer, but current capabilities of approximately 800 rows and

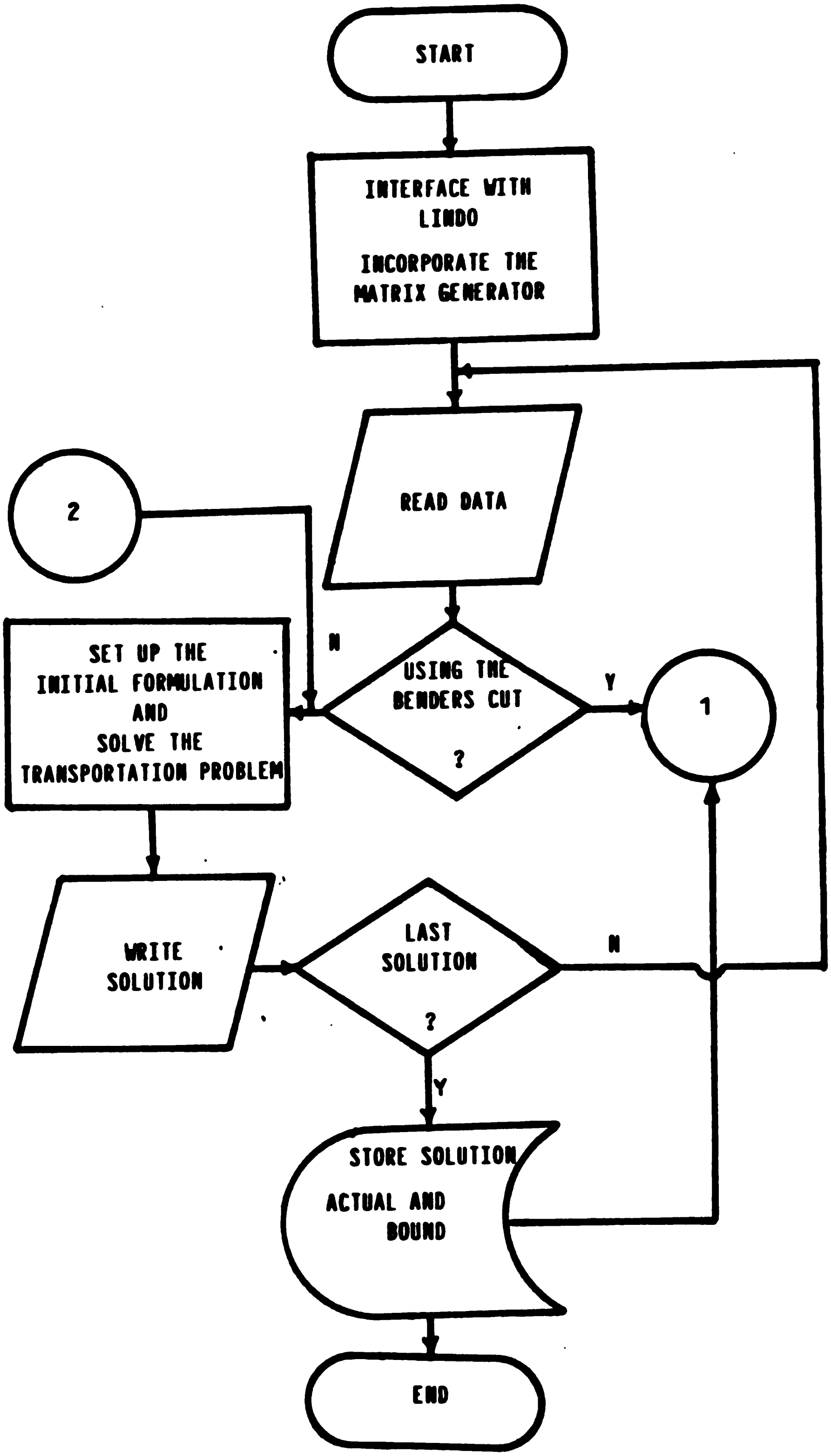


Figure 4.11. Main Frame Flow Chart for Facility Location-Allocation Study.

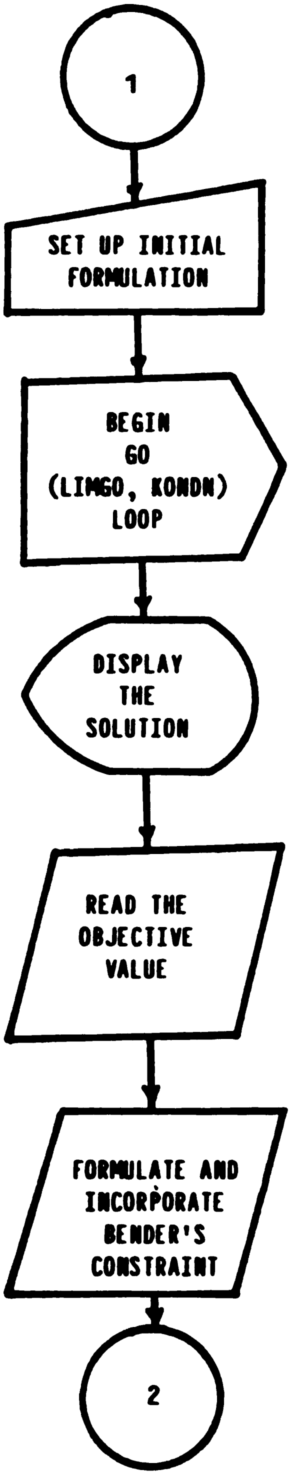


Figure 4.12. Flow Chart: Bender's Cut-HSJ Search.

4,000 columns.

(c) Ease of Use: HELP is available interactively.

(d) Multifaceted: LINDO has interfaces for MPS (industry standard) files, user-written FORTRAN subroutines, and general purpose text editors.

(e) Portability: Versions of LINDO running all major computer types (DEC 10, DEC 20, DEC VAX, IBM 370, Amdahl, Honeywell-Bull, Prime, Burroughs, CDC/Cyber, HP 3000, Harris and Sigma computers).

LINDO solves the integer programming problems by a branch-and-bound search procedure. In order to add a new constraint, a Bender's decomposition strategy (here referred to as Bender's cut) is used. This captures the advantage of the fact that each time an integer solution has been found, LINDO calls a subroutine NEWIP (actual, bound), but just before NEWIP is called, LINDO sets ACTUAL to the value of the objective function. A user-supplied version of NEWIP (Appendix I) is used to generate new constraints on the problem. The strategy is to add a constraint after an optimal solution has been found. This allows the incorporation of the hop-skip-jump routine (Section 2.6.1) for generation of alternatives provided by budgetary relaxation of the objective function value.

4.3. General Procedures and Model Assumptions

The cashew industry facility location problem defined in the previous sections naturally breaks down into two connected problems: the main problem (solved by interfacing a user-supplied subroutine USER) and the subproblem (solved by interfacing user-supplied subroutines USER(INPROB) and NEWIP(ACTUAL, BOUND)). The locational-allocational part forms the main problem. A solution to the main problem is a configuration of open facilities, at some sites, capable of processing all cashewnuts from the production centers and an associated allocation process in the form of a transportation problem. The subproblem is designed to answer some other adaptive "if" questions. Several assumptions have been made in formulating the cashew industry processing and handling model. Table 4.4 outlines the source, description, and assumptions of model variables.

The total costs that will be derived will not reflect the costs resulting from closing of plants. Since closing of plants rather than expansion of numbers of plants is being contemplated, capital costs are considered irrelevant and therefore are not part of system costs.

Table 4.4. Model Variables: Source, Description, and Assumptions.

Variable	Source/ Equivalence	Description and Assumptions
ACTUAL	User-supplied subroutine NEWIP. Dummy argument.	The value of objective function after solution has been achieved.
APPCOL	LINDO subroutine	e.g., APPCOL (NAME, NONZ, VAL, IRO, TRUBLE). Appends a column whose name is stored in the vector NAME which has NONZ coefficients stored in vector VAL with associated row numbers stored in vector IRO.
BEN(I)	User-supplied subroutine NEWIP.	Bender's constraint coefficient. Initialized zero. Relates to savings associated with opening of a preferred site.
CAP(I)	Subroutine USER.	Processing plant capacities array. Rated capacities (PC_{max}) in Table 3.6 apply to existing factories and 10,000-tonne capacity factory is used for to-be-established factories. Assumed expansion is from 50% to 100% of rated capacity.
C(I,J)	User-supplied subroutines USER, USER(INPROB), and NEWIP.	Allowed production center-processing plant assignment costs. Assignment costs include unit shipment cost, unit processing cost (λ). Appendix B (distance charts—d_{ij}'s), transportation costs per km ton of 26¢ for first five years of prediction and 52¢ for second five years are used. One linear approximation operating cost charge (fixed charge) is used. It should be noted that use of two or three segments in piecewise linear approximations, respectively, doubles or triples the number of processing plants to be considered in the formulation since segments break down to pseudo facilities. Figures 4.2-4.10 apply.
CIJMIN	Subroutine NEWIP	Assignment costs defining the closest (lowest) production center-processing plant combination.

Table 4.4 (continued).

Variable	Source/ Equivalence	Description and Assumptions
DEFROW	LINDO subroutine.	e.g., DEFROW (IDIR, RHS, IDROW, TRUBLE). Defines a row to the current formulation where IDIR=1 if < or minimization for row 1, 0 if =, and -1 if > or maximization for row 1; the right-hand side value of the row (+RHS), the row number assigned to this row (=IDROW) and the logical TRUBLE returned · TRUE.
D(I)	Subroutine USER	Production center production level (D(I)=b_i referred in Table 3.1). Levels are predicted in Table 4.1.
DP	Subroutine NEWIP	Summation of dual prices on the constraints for open plants.
FMND	Subroutine NEWIP	Minimum number of processing plants allowed open. Variable.
FMXO	Subroutine NEWIP	Maximum number of processing plants allowed open. Variable.
FXD	Subroutine USER referred also as F(I) in subroutine USER(INPROB).	Fixed costs (also referred to as F_i or F_i' in the text) for the processing plants. Table 3.6 and Figures 4.2-4.10 apply.
GIANT	Subroutine USER (INPROB)	Control argument. Aborts solution if limit exceeded.
GLOBAL	Subroutine NEWIP	Accumulates cost of current optimal solution.
GO	LINDO subroutine	e.g., GO (LIMGO, KONDN). Command to go and solve the problem. LIMGO defines the limit on number of pivots (LIMGO=0 or default specifies limits set by LINDO: KONDN specifies on return solution status (4=optimal, 5=unbounded, 2=infeasible).
I	All subroutines.	Potential processing plant sites (I=1,2, ...,NP or M). Feasible set approach is assumed and all potential production center sites in Table 4.1 can be potential plant sites. Processing plants are regarded as supply points in this study supplying their processing capacities.

Table 4.4 (continued).

Variable	Source/ Equivalence	Description and Assumptions
INIT	LINDO subroutine	Reinitializes storage in preparation for new problem.
INSERT	LINDO subroutine	e.g., INSERT(I, J, AMT, NOADD). Replaces element in row I, column J of the matrix. If NOADD=1, then AMT replaces the old value at I,J; otherwise AMT is added to old value.
J	All subroutines	Potential production center sites (J=1,2,...,NC or N). Refer to Table 4.1. In this study, production centers are regarded as demand points; their production levels create a demand for a processing capacity.
M	All subroutines	Number of supply points (processing plants).
N	All subroutines	Number of demand points (production centers).
NC	Subroutine USER	Number of customers (demand points).
NDIM1	Subroutine USER	Limit on the number of processing plants for which the subroutine is designed.
NDIM2	Subroutine USER	Limit on the number of production centers for which the subroutine is designed.
NP	Subroutine USER	Number of processing plants.
OUTSOL	LINDO subroutine	Prints a standard solution report.
REPVAR	LINDO subroutine	e.g., REPVAR (J, PRIMAL, DUAL). Returns the value of variable J in PRIMAL and its reduced cost in DUAL.
SBCOST	Subroutine NEWIP	Accumulates the subproblem or transportation costs.
X(I,J)	Subroutine USER	Amounts of cashewnut shipment from production center J to processing plant I.

Table 4.4 (continued).

Variable	Source/ Equivalence	Description and Assumptions
Y(I)	Subroutine USER	Equal to 1 if potential plant site I has been designated open; equal to 0 otherwise.
Z	Subroutine USER(INPROB)	Defines the objective function to be minimized.

CHAPTER 5

SENSITIVITY ANALYSIS

5.1. General

In an effort to answer some of the "adaptive if" questions, the model was run for several model inputs designed to highlight the issue under study. Table 5.1 shows the setting of the model inputs for each run for the respective "adaptive if" issue. The program was run on the CDC Cyber 750 under the Michigan State University Hustler System.

5.2. Effects of Changes in Demand

Table 5.2 shows in tableau form the allowed combination coefficients that were used in arriving at the location-allocation solutions. Routinely, the omitted coefficients, C_{ij}'s (designating the nonpreferred production center-processing plant combinations), were assigned a very large number, thus rendering them unacceptable routes. Table 5.3 shows the optimal or near optimal solutions to the cashew industry in relation to changes in predicted production center production levels (demand levels). Figures 5.1 to 5.6 show the allocation of production centers to processing plants for six years (1982-83 to 1987-88). As summarized in Table 5.4, based on the 1982-83 season figures, a fifteen

Table 5.1. Sensitivity Analysis Variable Inputs: Model Verification Parameters.

"Adaptive If" Issue	Run #	Production Year						Unit Transportation Cost ($/tonne/km)		Utilized Factory Capacity (%)			Number of Forced Facilities in Solution		
		1	2	3	4	5	6	0.26	0.52	50	75	100	0	1	2
Changing Demand	1.1	x						x				x	x		
	1.2		x					x				x	x		
	1.3			x				x				x	x		
	1.4				x			x				x	x		
(Production Levels)	1.5					x		x				x	x		
	1.6						x		x			x	x		
Capacity Changes	2.1	x						x		x			x		
	2.2	x						x			x		x		
Forcing Facilities into Solution	3.1	x						x				x		x	
	3.2	x						x				x		x	
	3.3	x						x				x			x

Table 5.2. Coefficients for the Allowed Plant-Production Center Combinations - Assignment Costs (C(I,J)).

PLANT-FACILITY (I)			PRODUCTION CENTER (J) ($)																			
#	CAP (000)	FXD (000)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	SAME FOR ALL RUNS	SAME FOR ALL RUNS											20.5	25.1	40.2	100.0	60.5	12.7	216.5	432.8	100.0	Tanita I
2													27.7	31.9	47.0	93.8	60.5	12.7	223.3	439.6	106.8	Tanita II
3													45.5	22.1	65.2	125.0	91.7	25.2	191.6	407.9	75.1	Kibaha
4										51.3						61.2	115.3		377.4		254.1	Kilwa
5			54.4			28.9	37.8			100.2												Lindi
6			66.9	42.0	42.0	37.8	32.1	33.7	100.2	137.7												Mtama
7					24.8		33.7	18.1	66.9		124.7	249.2										Nachingwea
8				36.1	27.8		41.8	31.4	91.2		100.1	224.9								459.9		Masasi
9				21.0	36.1		41.8	60.5	127.1													Newala I
10				21.0	36.1		41.8	60.5	127.1													Newala II
11			25.2			54.3																Likombe
12			25.2			54.3																Mtwara
13											26.2	125.0										Tunduru
			Mtwara	Newala	Masasi	Lindi	Mtama	Nachingwea	Liwale	Kilwa	Tunduru	Songea	Kisarawe	Kibaha	Bagamoyo	Utete	Mafia	Dar es salaam	Tanga	Mbeya	Morogoro	

Table 5.3. Effects of Predicted Changes in Production Center Levels (Demand) on Plant Locations' Annual Systems Costs and Routing of Cashew and Its Products for the 1982-83 to 1986-87 Seasons.

Production Year	Estimated Production (tonnes)	Plants in Solution (Optimal or Near Optimal)	Raw Cashewnut Processed (tonnes)	Routing Plan	System Costs ($000)		Cost Contribution (%)	
					Sub*	Total**	Fixed	Assigned
1982-83	32,473	(3) Kibaha	10,000	Figure 5.1	3,324.899	3,332.088	52	48
		(5) Lindi	5,000					
		(7) Nachingwea	5,000					
		(9) Newala I	4,996					
		(10) Newala II	9,506					
1983-84	49,051	(3) Kibaha	8,648	Figure 5.2	4,514.419	4,524.164	46	54
		(4) Kilwa	2,928					
		(7) Nachingwea	5,000					
		(8) Masasi	10,000					
		(9) Newala I	10,000					
		(10) Newala II	6,294					
		(12) Mtwara	3,448					
1984-85	50,576	(3) Kibaha	8,917	Figure 5.3	4,581.553	4,589.956	46	54
		(4) Kilwa	3,020					
		(7) Nachingwea	5,000					
		(8) Masasi	10,000					
		(9) Newala I	7,268					
		(10) Newala II	10,000					
		(12) Mtwara	6,368					

*Excludes cost of shipment to part.
**Includes cost of shipmnet to port.

Table 5.3 (continued).

Production Year	Estimated Production (tonnes)	Plants in Solution (Optimal or Nonoptimal)	Raw Cashewnut Processed (tonnes)	Routing Plan	System Costs ($000)		Cost Contribution (%)	
					Sub*	Total**	Fixed	Assigned
1985-86	53,957	(3) Kibaha	9,513	Figure 5.4	4,731.069	4,741.653	44	56
		(5) Kilwa	3,222					
		(7) Nachingwea	5,000					
		(8) Masasi	10,000					
		(9) Newala I	9,424					
		(10) Newala II	10,000					
		(12) Mtwara	6,793					
1986-87	59,559	(3) Kibaha	10,000	Figure 5.5	5,291.565	5,302.122	40	60
		(4) Kilwa	4,039					
		(6) Mtama	5,000					
		(7) Nachingwea	4,995					
		(8) Masasi	10,000					
		(9) Newala I	10,000					
		(10) Newala II	10,000					
		(12) Mtwara	5,516					
1987-88+	68,022	(3) Kibaha	9,918	Figure 5.6	8,028.629	8,051.007	47	53
		(6) Mtama	5,000					
		(7) Nachingwea	5,000					
		(8) Masasi	10,000					
		(9) Newala I	10,000					
		(10) Newala II	10,000					
		(11) Likombe	8,138					
		(13) Tunduru	3,823					
		(14) Tanga	1,850					
		(15) Utete	4,286					

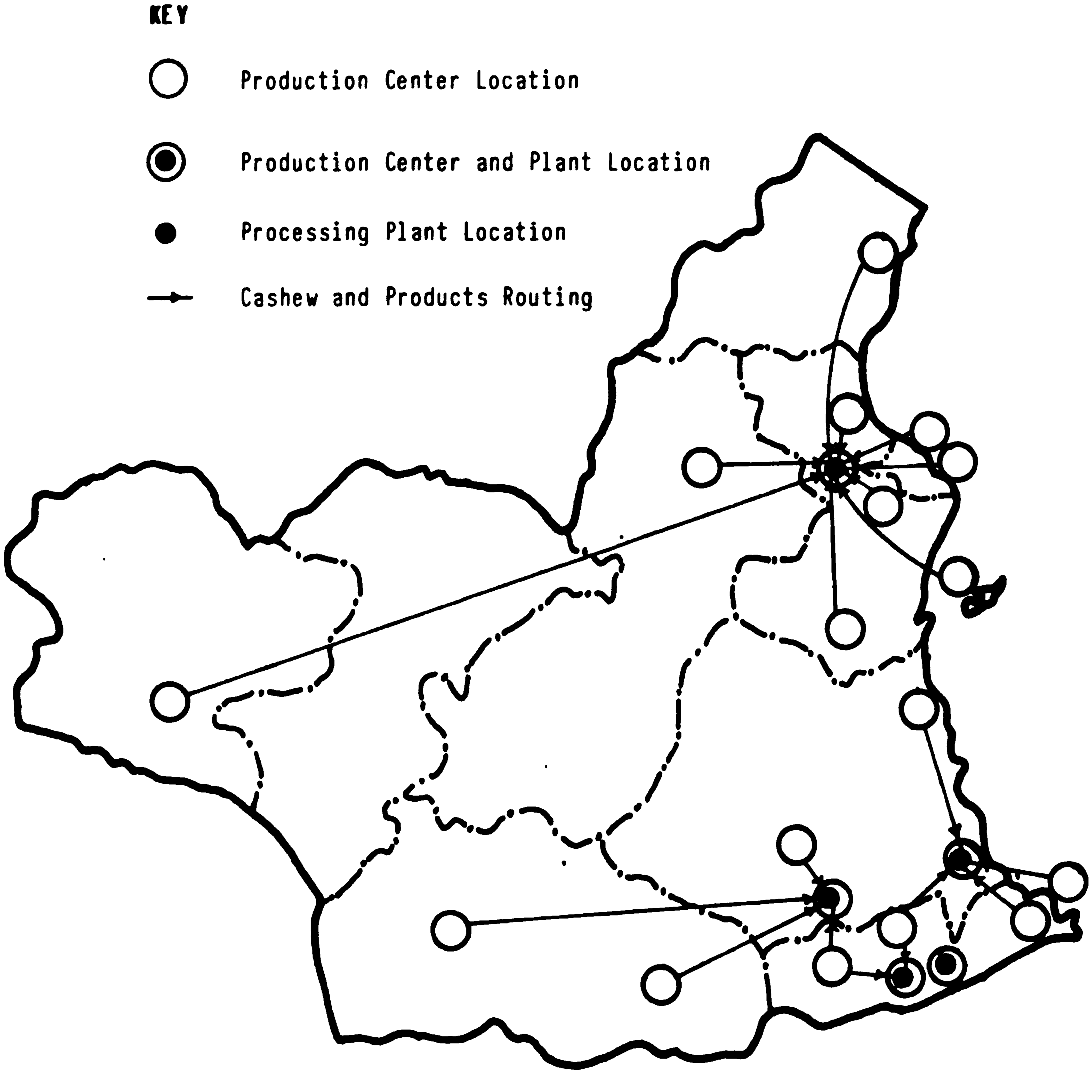


Figure 5.1. Facility Location-Allocation Plan and Raw Cashewnut Routing Plan (1982-83).

Note:
1. Production level - 32,473 metric tons.
2. Plants in solution: Kibaha, Nachingwea, Lindi, Newala I, and Newala II.
3. 80% of cashew production comes from the southern region, 20% from the northern region (cf., plant ratio 4:1).

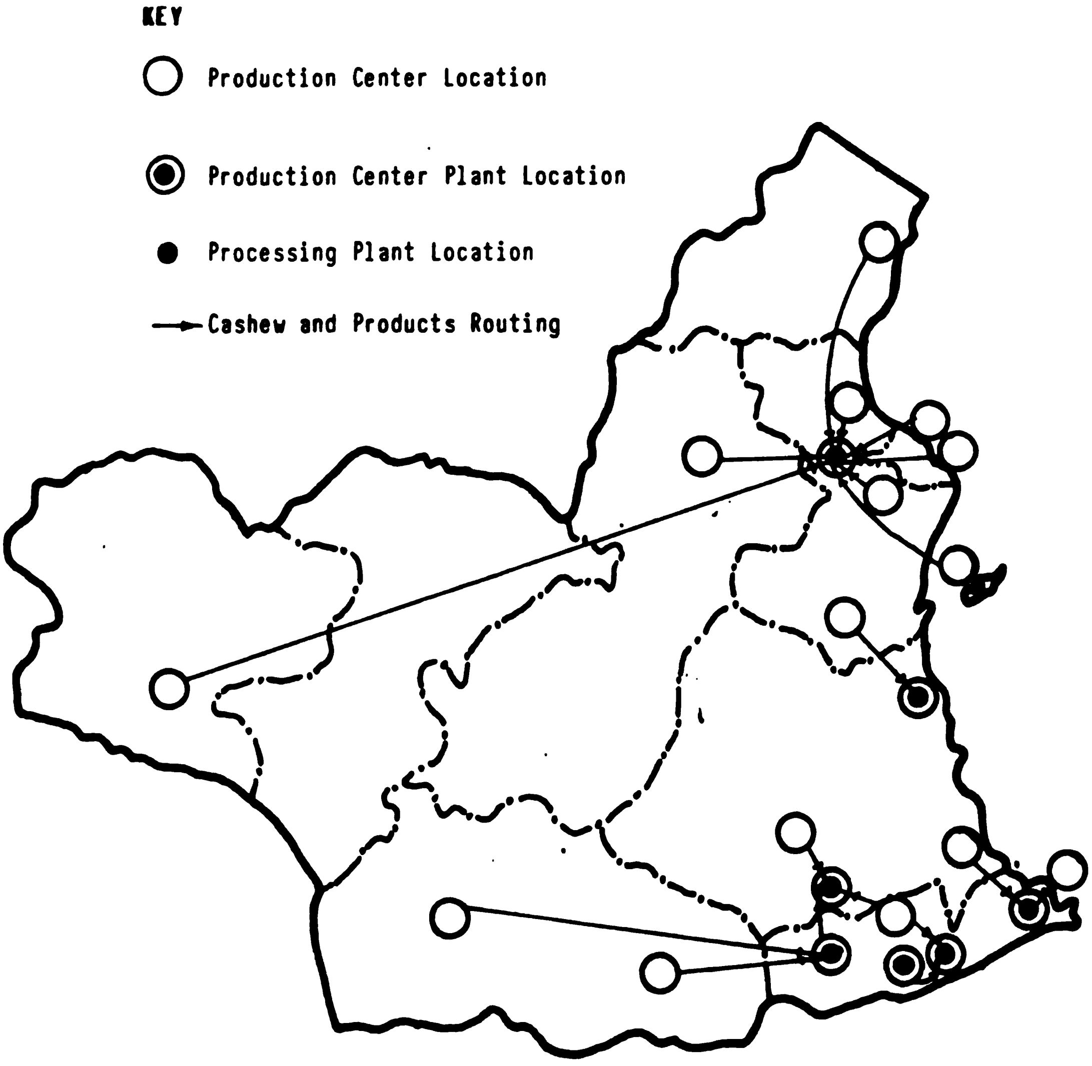


Figure 5.2. Facility Location-Allocation Plan and Raw Cashewnut Routing Plan (1983-84).

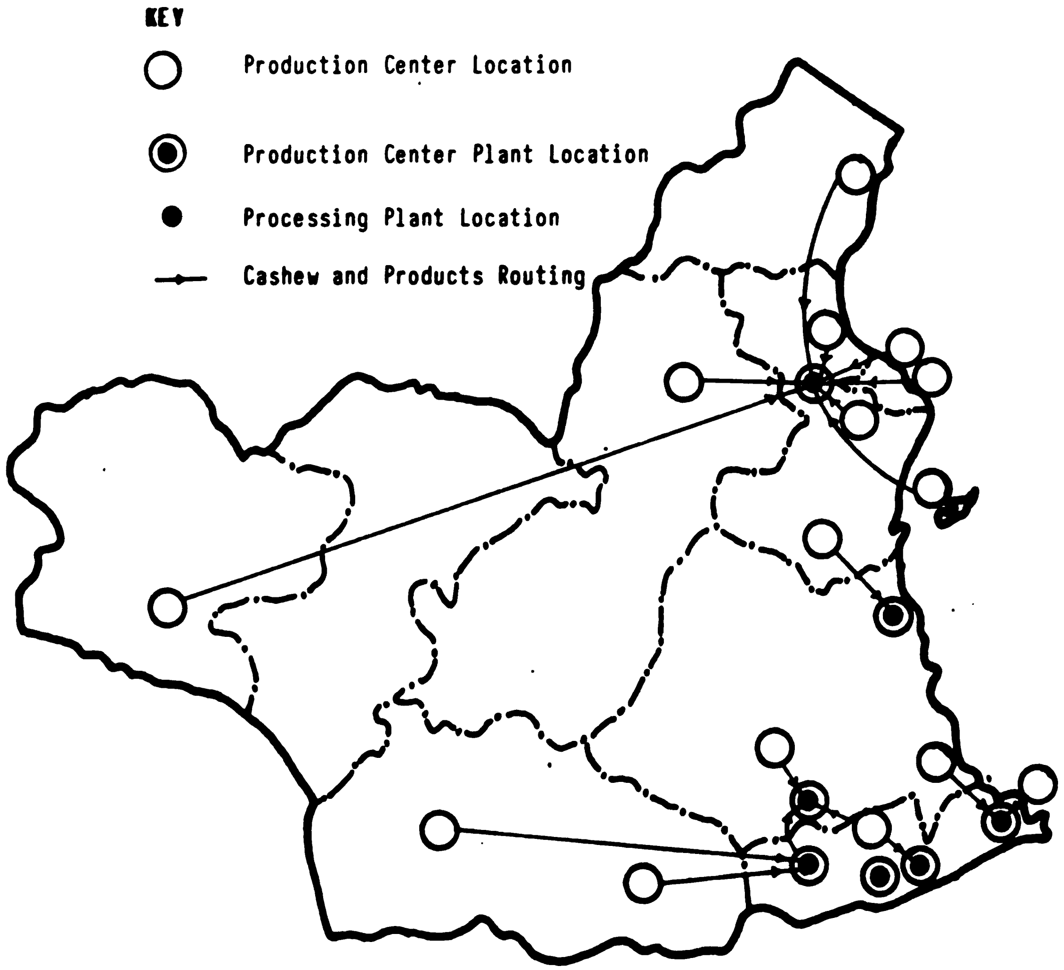


Figure 5.3. Facility Location-Allocation Plan and Raw Cashewnut Routing Plan (1984-85).

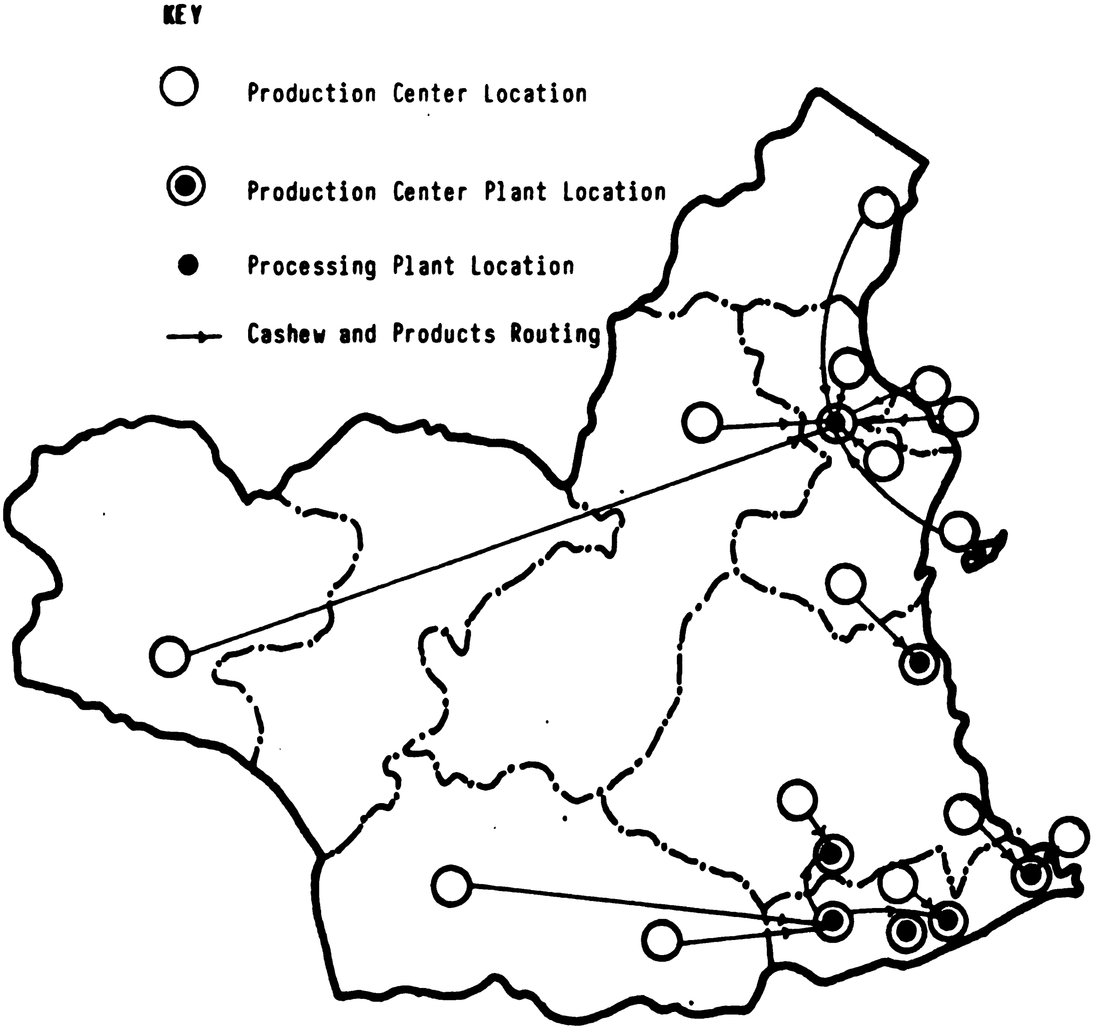


Figure 5.4. Facility Location-Allocation Plan and Raw Cashewnut Routing Plan (1985-86).

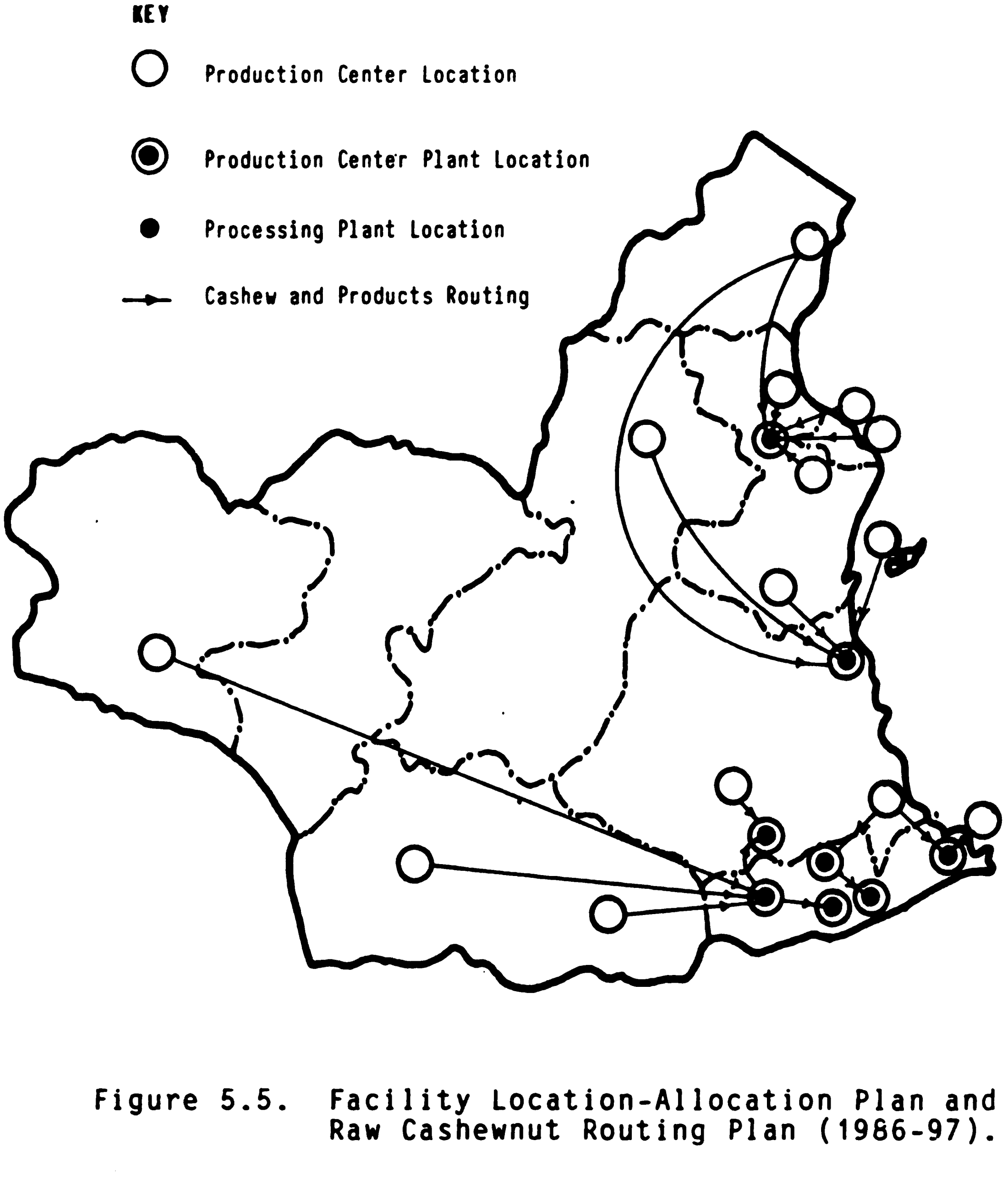


Figure 5.5. Facility Location-Allocation Plan and Raw Cashewnut Routing Plan (1986-97).

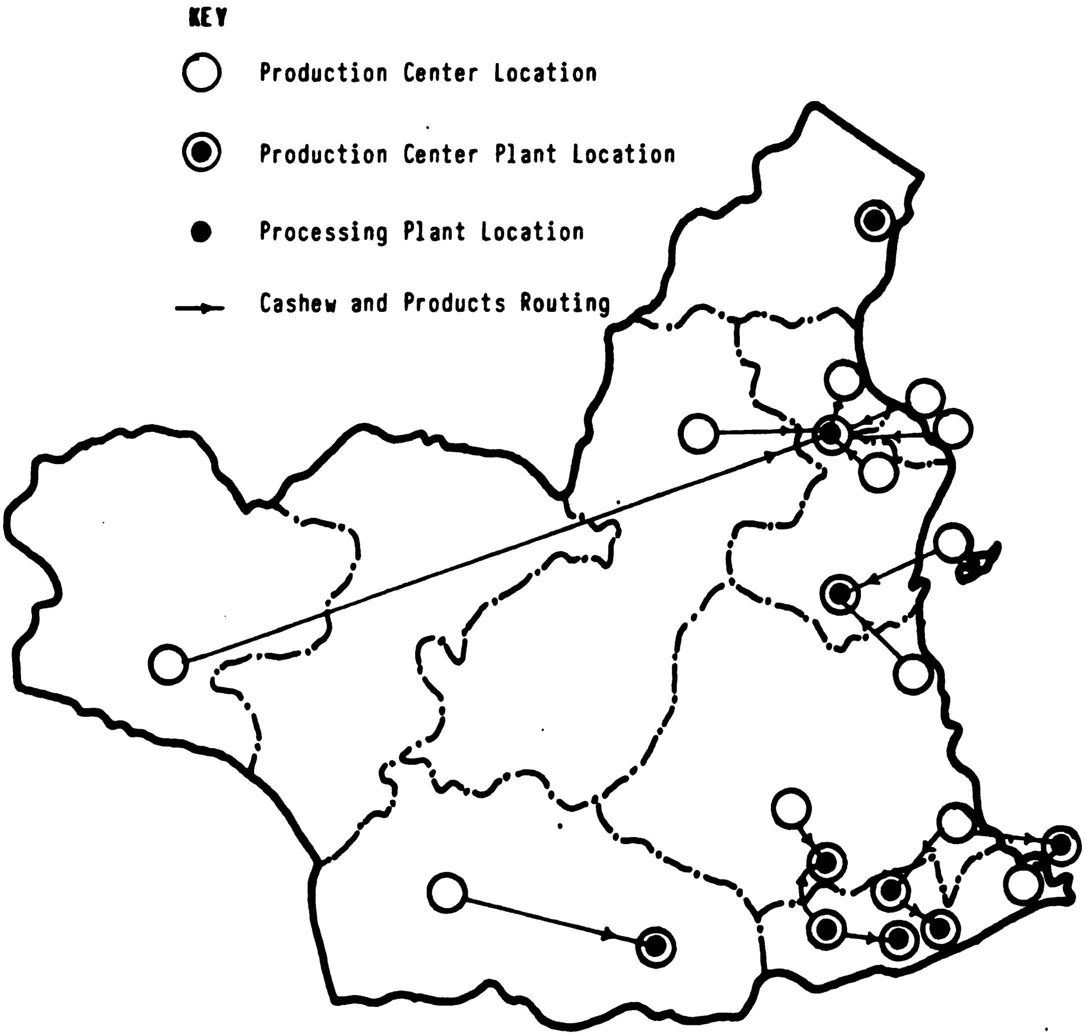


Figure 5.6. Facility Location-Allocation Plan and Raw Cashewnut Routing Plan (1987-88).

Table 5.4. Demand Change Summary of Effects.

Year	Increase in Demand (%)	Number of Plants	Increase in Total System Cost+ (%)
1982-83*	–	5	–
1983-84	51	7	37
1984-85	56	7	39
1985-86	66	7	44
1986-87	83	8	61
1987-88**	109	10	144

*Reference base (32,473 metric ton production level)
**Based on 52¢/tonne-km transportation cost
+Increase in total system cost does not necessarily reflect the resulting profits to CATA or prices the farmers get.

percent change in cashew production did not lead to a change in location or number of processing plants, and there was only a seven percent change in total system cost. This is an indication of the robustness of the solutions between the 1983-84 and 1985-86 seasons.

A configuration of processing plants shows preference for the southern region in all solutions, and this is consistent with the fact that 80% of the cashew production comes from the south. Appendix K shows the shipments for each corresponding routing plan. Routing from a production center with a plant located at that site to another plant may seem more a "shuffle," but this feature may be utilized to an advantage such that the production in the domain of one production center but close to the designated processing plant in another center's domain can be shipped to the assigned plant directly instead of shipping to its center first. This may result in further reduction in transportation costs. On average, the contribution to the total system cost is 54% assignment costs (including transportation and processing costs—variable costs) and 46% fixed costs. This implies that the use of either cost category alone in solving the facility location-allocation problem may be inadequate and probably result in misleading solutions.

Robustness of locations to possible futures may be highlighted by calculating what is referred to in this study as "robustness index (RI)." This index does not necessarily have the same meaning as that used by statisticians. The RI of each location can be calculated by the ratio:

$$RI = \frac{\text{Number of sets in which location appears}}{\text{Total number of sets}}$$

The assumption is that the location with the highest robustness index should be chosen as the first location to be utilized. Where two sites are close together, they become alternatives. For sites with similarly high RI scores, consideration of short-run costs incurred by each possible decision and the stability of the locations should be made. Table 5.5 shows an example summary of the above procedure based on the near optimum solutions for the 1982-83 to 1987-88 cashew production seasons (see Table 5.3).

5.3. Evaluation of Facility Capacity Changes

Three levels of capacities were assumed and incorporated into the model. Table 5.6 shows the effect of these three capacity levels on plant location, allocation of production centers to processing plants, and system total cost based on the 1982-83 season demand. There is little locational difference for plants in the solution between 75% and 100% processing capacity, but a large difference exists between 50% and 75% capacity. This is mainly a result of a more concentrated production in the southern part of the cashew growing region, forcing more plants to be open in that area due to drops in plant capacities. A shift from 50% to 75% and 100% capacity utilization resulted in,

Table 5.5. Robustness Index (RI) for the Six Sets of Solutions.*

Plant Location	RI
Kibaha	1.00
Nachingwea	
Newala I	
Newala II	
Masasi	0.83
Kilwa	0.67
Mtama	0.33
Mtwara	
Lindi	0.17
Likombe	
Tunduru	
Tanga	
Utete	

*Only processing plants in the solution are reported. A high RI location should be considered first in opening of plants and considered last in a closing strategy. The converse is true for low RI locations.

Table 5.6. Effects of Cashewnut Processing Plant Capacity Changes on Plant Location, Allocation, and Total System Cost.*

Item	Plant Capacity Utilized (%)		
	50	75	100
Number of Plants	9	5	5
Plant Location	(2) Tanita II (4) Kilwa (5) Lindi (6) Mtama (7) Nachingwea (8) Masasi (9) Newala I (10) Newala II (13) Tunduru	(1) Tanita I (5) Lindi (8) Masasi (9) Newala I (10) Newala II	(3) Kibaha (5) Lindi (7) Nachingwea (9) Newala I (10) Newala II
Total System Cost ($)	4,585,980	3,477,514	3,332,088
Allocation of Centers	Figure 5.7	Figure 5.8	Figure 5.1

*Based on 1982-83 production figures (demand).

respectively, 24% and 27% increases in total system cost, whereas a shift from 75% to 100% capacity utilization resulted in only a 4% increase. Figures 5.7 and 5.8 show facility location-allocation plans with 50% and 75% plant capacity utilization, respectively.

5.4. Effects of Forcing Certain Facilities into Solution

Most decisions in public sector problems are made in a political arena, probably with little bearing on budgetary constraints. A procedure for forcing certain facilities may therefore provide a device for analyzing such decisions. In this study, the facility location is forced into solution by assigning a very small C_{ij} value (e.g., one is used in this study), in effect, making the route the least expensive. Table 5.7 shows three examples of forced facility systems; Figures 5.9-5.11 depict routing plans. Subsystem costs do not reflect realistic costs of the system due to the imposed C_{ij}'s. Actual subsystem costs are given and compared to the unforced solution system. One should note that a higher cost penalty tends to be associated with locations of low robustness. Forcing Mtwara (RI=.33) resulted in a 30% subsystem cost increase; forcing Tanita II (RI=low) alone resulted in a 39% increase and even a larger increase (130%) if both Tanita I and II were forced into solution. In this case, it is not easy to directly assess the effect of these increases on profits to CATA or their contribution to prices farmers receive for their cashewnuts.

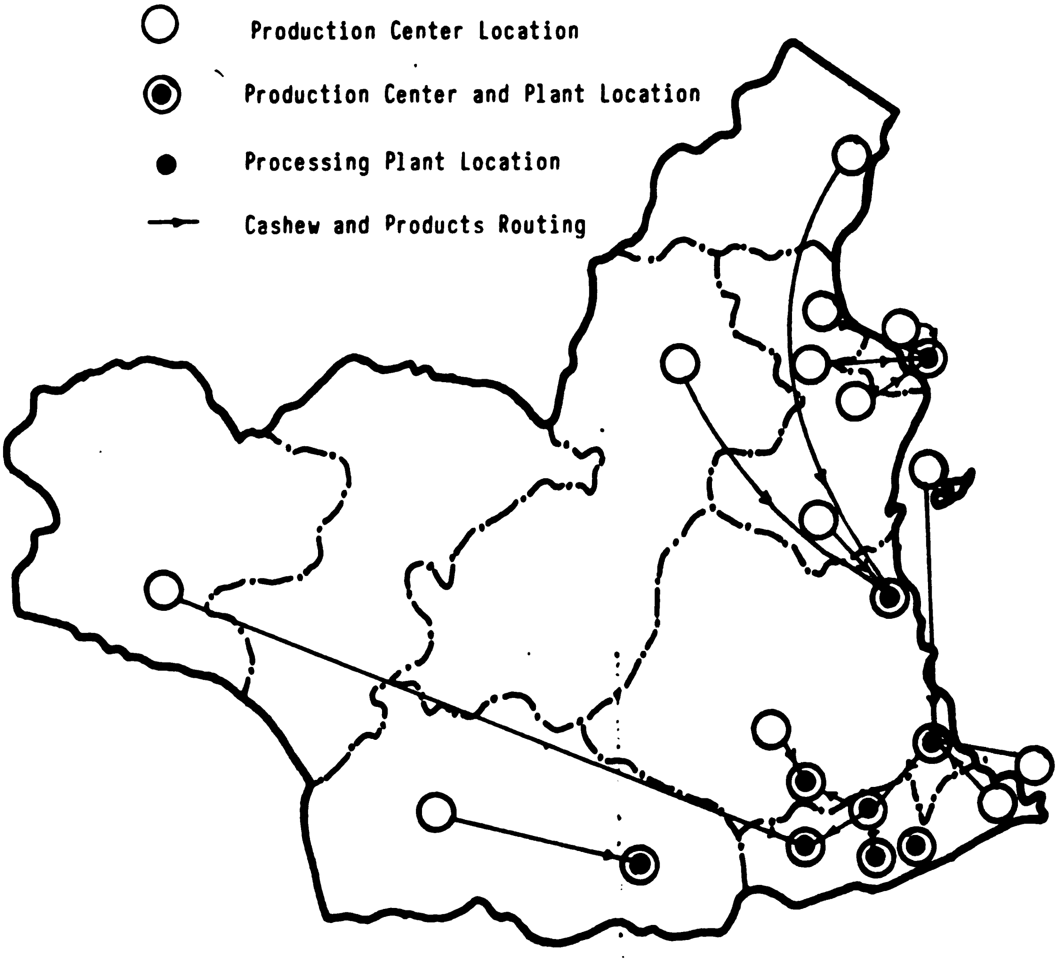


Figure 5.7. Facility Location-Allocation Plan with 50% Plant Capacity Utilization.

Based on 1982-83 production figures.

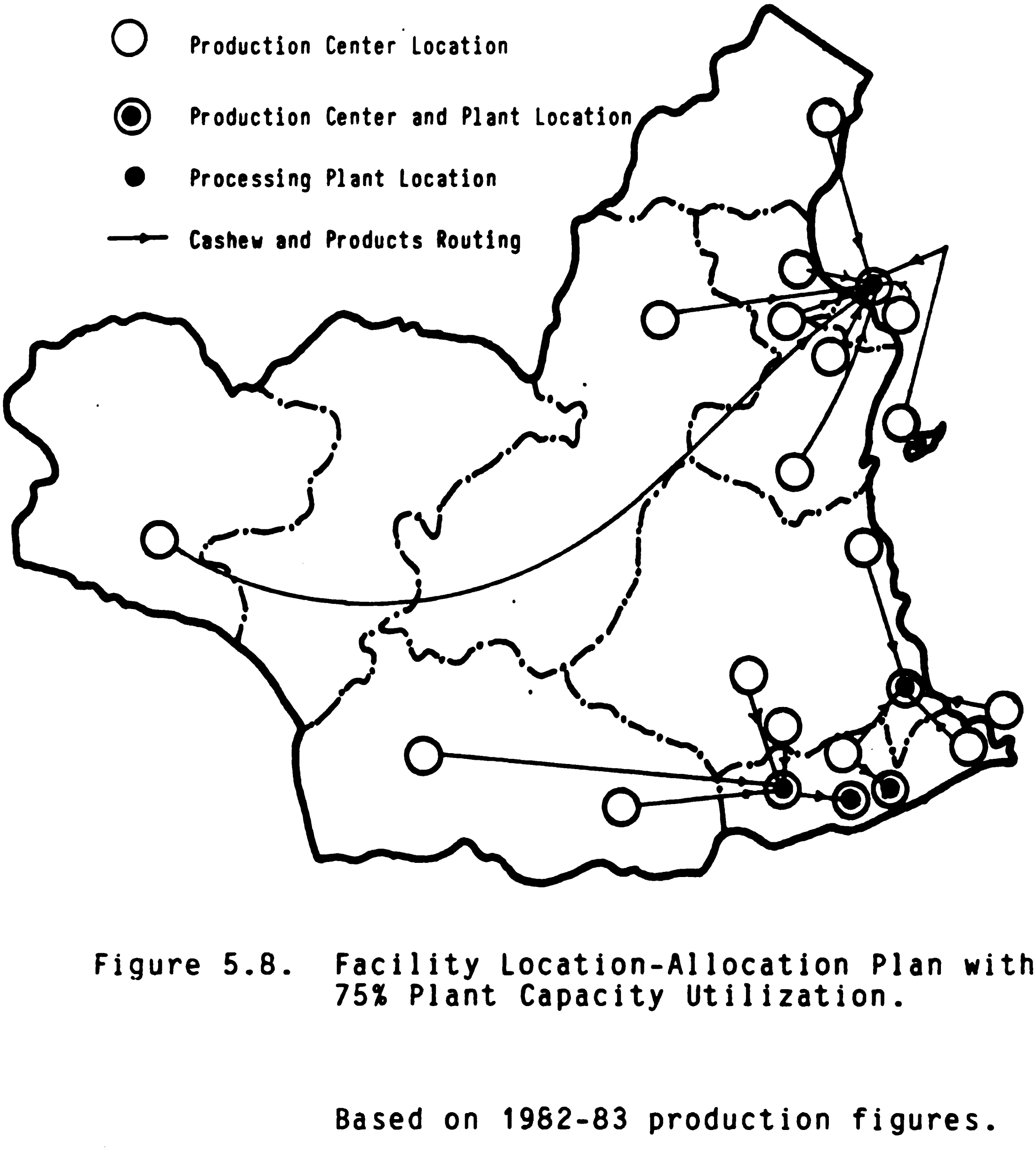


Figure 5.8. Facility Location-Allocation Plan with 75% Plant Capacity Utilization.

Based on 1982-83 production figures.

Table 5.7. Effects of Forcing Certain Key Facilities into Solutions.*

Run Number	Facilities in Solution	Inbound Shipment (tonnes)	Routing Plan	Forced Subsystem Cost ($000)	Actual Subsystem Cost ($000)	Cost Increase Compared to Unforced Solution+ (%)
3.1	(2) Tanita II**	11,861	Figure 5.9	2,413.794	4,619.786	39
	(4) Kilwa	1,287				
	(6) Mtama	4,545				
	(7) Nachingwea	5,000				
	(9) Newala I	9,641				
3.2	(2) Tanita II	7,594	Figure 5.10	3,237.065	4,319.834	30
	(5) Lindi	5,000				
	(6) Mtama	5,000				
	(7) Nachingwea	5,000				
	(11) Likombe	1,879				
	(12) Mtwara**	8,000				
3.3	(1) Tanita I**	12,000	Figure 5.11	1,921.933	7,639.220	130
	(2) Tanita II**	12,000				
	(3) Newala II	8,473				

**Forced facility location.

*1982-83 cashew production figures are used.

+Unforced solution subsystem cost is $3,324,899.

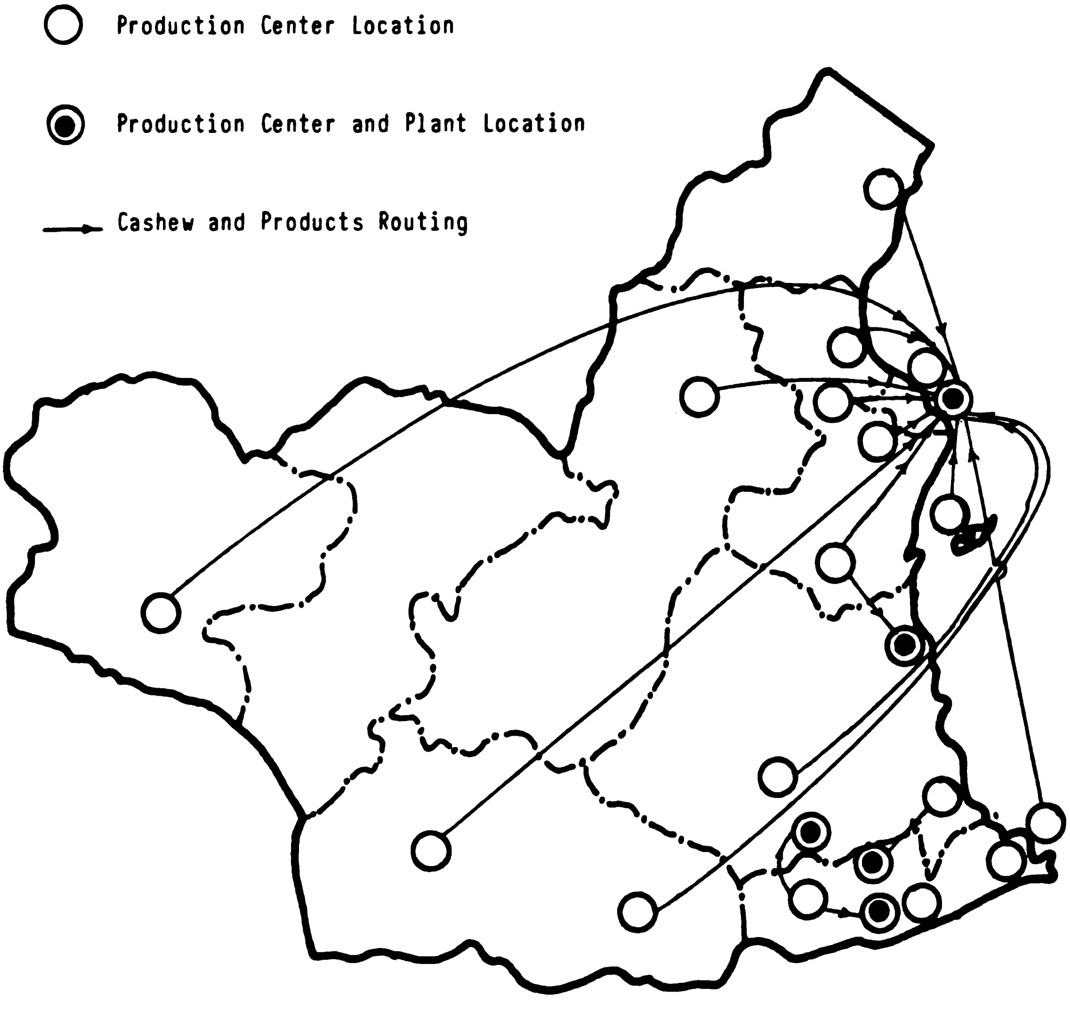


Figure 5.9. Facility Location-Allocation Plan: Tanita II Forced into Solution (1982-83 season production figures).

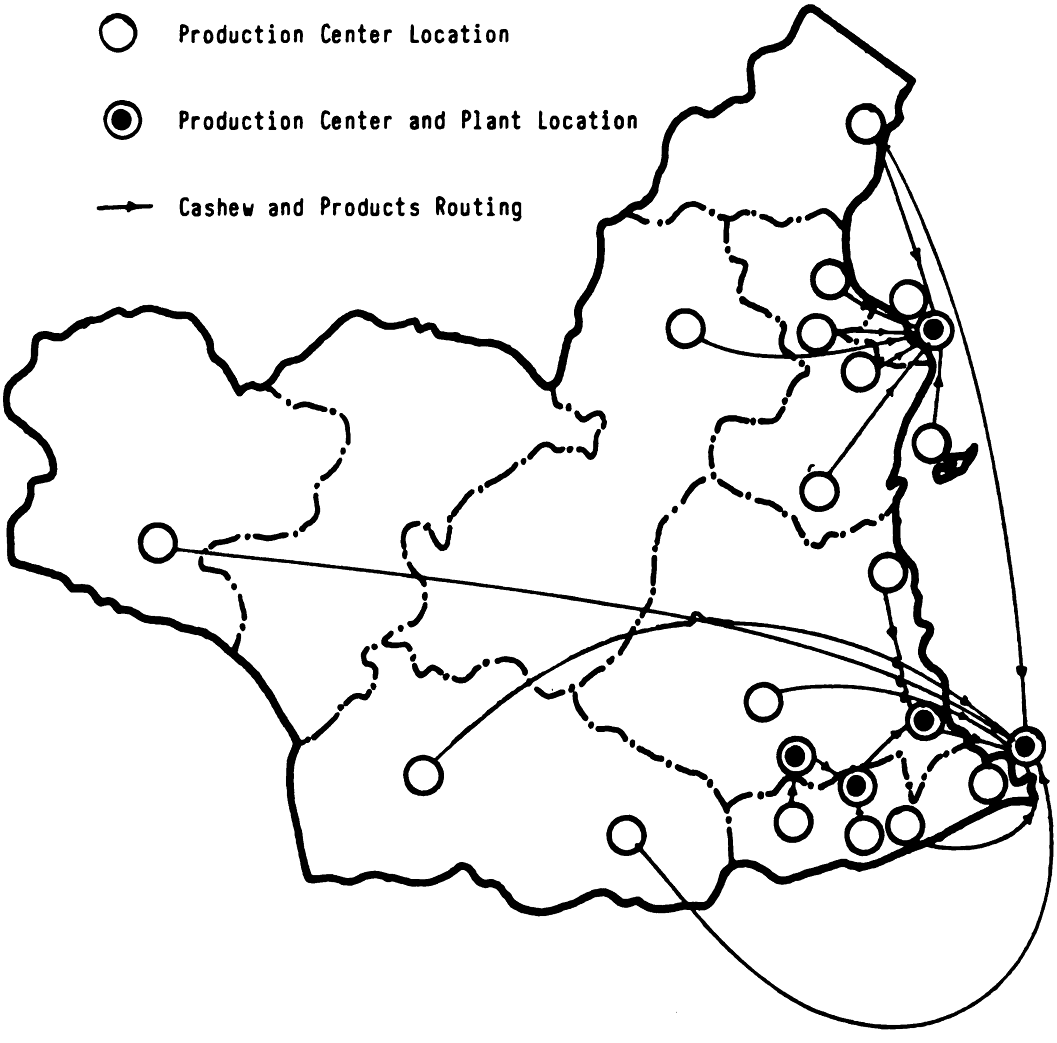


Figure 5.10. Facility Location-Allocation Plan: Mtwara Forced into Solution (1982-83 season production figures).

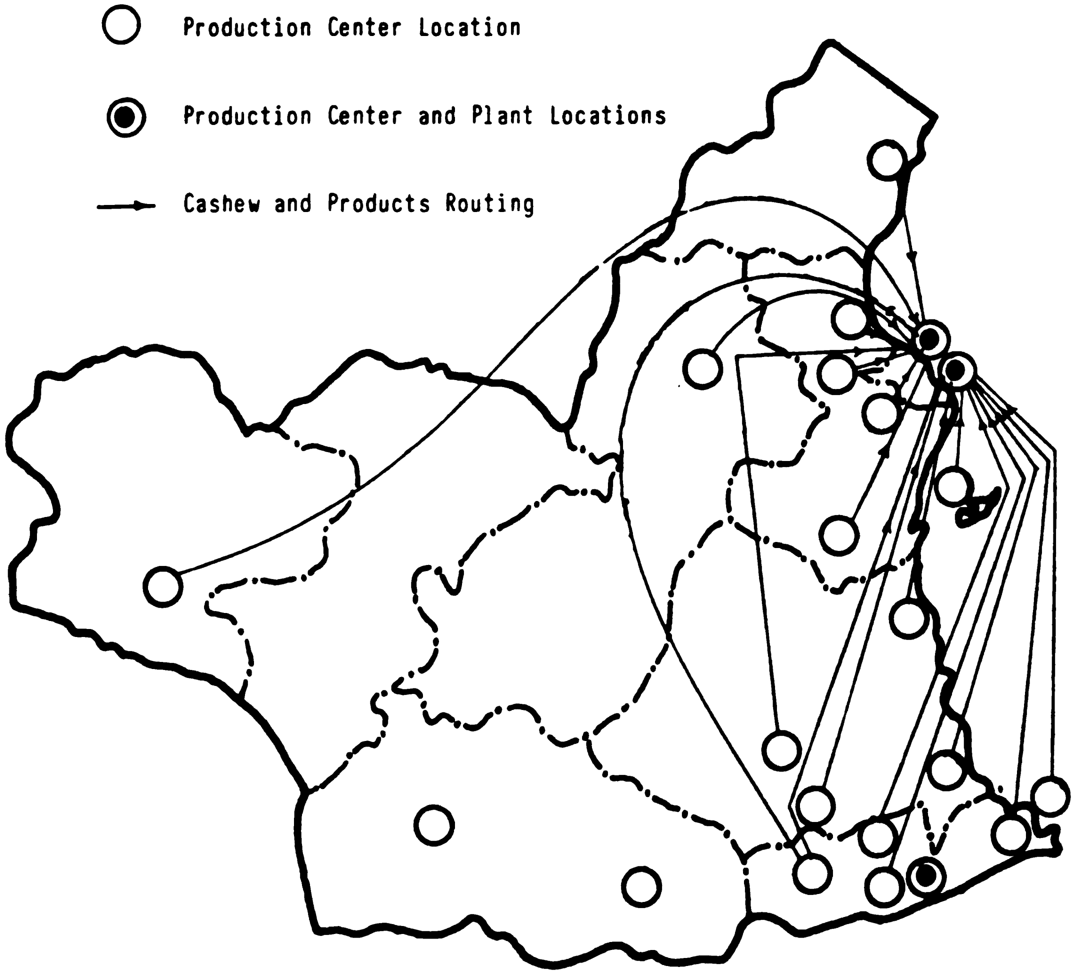


Figure 5.11. Facility Location-Allocation Plan: Tanita I and II Forced into Solution (1982-83 season production figures).

5.5. Computational Experience

User subroutines were written in FORTRAN V to implement the interfacing with computer code LINDO. Due to a financial "squeeze," the code was only applied to solve fixed charge capacitated problems. Because integer problems tend to be difficult to solve, an addition of the Bender's cut and tightening of formulations by specifying only the allowed C_{ij}'s was found helpful in reducing the central processing unit time (CPU). Table 5.8 shows a summary of computational requirements for solving the fixed charge capacitated facility location problems run on CDC CYBER 750. The computer time in this study compares favorably with that reported in other studies (cf. Soland, 1974). All problems were solved to optimum.

One important aspect to note is that increases in the matrix size may lead to intolerably large amounts of computer time. With such large problems, use of data files (such as mathematical programming systems format files used in industry (MPS files) for data input) need to be contemplated.

On LINDO, several observations may be made. A standard solution report by LINDO also includes items that may be used in sensitivity analysis, i.e., reduced costs and dual prices. Reduced cost is interpreted as the rate at which the objective function value will deteriorate if a variable currently at zero is arbitrarily forced to increase a small amount. If the units of the objective function are in

Table 5.8. Computational Requirements for Solving the Fixed Charge Problems.

Problem	m	n	CPU Time, s	PP Time, s	Computer Terminal Time (hours)
1	3	4	.74	14.3	.14
2	4	7	.84	16.7	.16
3	13	19	2.31	28.9	.42
4	13	19	2.08	27.9	.39
5	13	19	1.94	28.6	.47
6*	4	6	0.4	—	—
7*	6	8	4.5	—	—

*Compare Soland (1974) for similar fixed charge problems with zero fixed costs.

n = supply center
m = demand center

Note: Average central memory usage for the 13x19 problem was 2.43 W-H. Cost for obtaining one solution ranged from $3.80 (RG1) to $12.50 (RG3).

dollars and the units of the variable are tonnes/year, then the units of reduced costs are dollars per tonne/year. Its value is the amount by which the variable profit contribution of the variable must be improved before the variable in question would have a positive value in the optimal solution. A variable in optimal solution, of course, will have a zero or negative reduced cost.

A dual price associated with each constraint is the rate at which the objective function value will improve as the right-hand side (RHS) or constant term of the constraint is increased a small amount. The convention used in LINDO is that a positive dual price means that increasing the RHS in question will improve the objective function value while a negative dual price means increasing the RHS will cause the objective value to deteriorate. A zero dual price implies that small changes in the RHS will have no effect on the solution value.

LINDO does not provide for senstivity (range) analysis for integer solutions due to the fact that the last integer solution found in the branch-and-bound search is not retained internally for further reference. This is certainly a negative on LINDO. It should also be noted that LINDO does not do any scaling of the LP matrix. Therefore, the user needs to scale the rows and columns to avoid numerical problems. The rule of thumb is that nonzero coefficients should not be less than 0.0001 or more than 10^5. LINDO assumes that the data are accurate.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The study reviewed handling and processing of cashewnuts in Tanzania, and, where appropriate, comparison was made to other cashewnut-producing countries. The facility location-allocation model was developed and solved using a LINDO code. Bearing in mind the assumptions put forth and accepting the fact that it is insight rather than numbers that is important, one can say the following from the study:

(1) (a) Cashewnut processing facility capacity changes showed a larger increase in total system costs between 50% to 75% compared with 75% to 100% capacity utilization. Above 75%, processing facility utilization seemed to be a utilization factor to aim toward under the circumstances. It should be pointed out, however, that 75% and 100% utilization solutions only provided five open plants as opposed to nine open plants with 50% utilization. Thus, a 50% utilization does answer some public-sector criteria, such as provision of a wider rural industrial base, income distribution to rural areas, and avoidance of the risks that pertain to centralization of facilities. Yet this

does not rule out problems of decentralization, such as those of communication and facility duplication (e.g., special equipment and specially skilled labor).

(b) The robustness index (not necessarily as defined in statistics), based upon an optimum or near optimum solution set in static problems, can be used to sort out the robustness of a location in relation to other locations. In case of initial facility location problems, the so-called "greenfields" situation (the RI ranking for the potential facilities based on projected demands) provides insight to the facility location-allocation implementation strategy. In the case of a presence of existing facilities, RI ranking can be used in the implementation of locational strategy, with present sites as fixed bases from which to move or with possibility of dropping old sites and opening new ones over a longer planning horizon.

(2) (a) The model effectively provides optimal or near optimal solutions to facility location-allocation problems, allowing for, where necessary, split shipments.

(b) The "allowable" processing plant-production center combination feature of the model for the input of assignment costs is very helpful in providing some answers to public sector issues, such as decentralization requirements and in stipulating effects of such issues as closures due to weather.

(c) Although the interactive aspect of the model permits closer scrutiny of data inputs, with large problems, the process nevertheless tends to be tedious. Therefore, use of data files for data inputs may be necessary.

Based on the foregoing discussion, it is recommended:

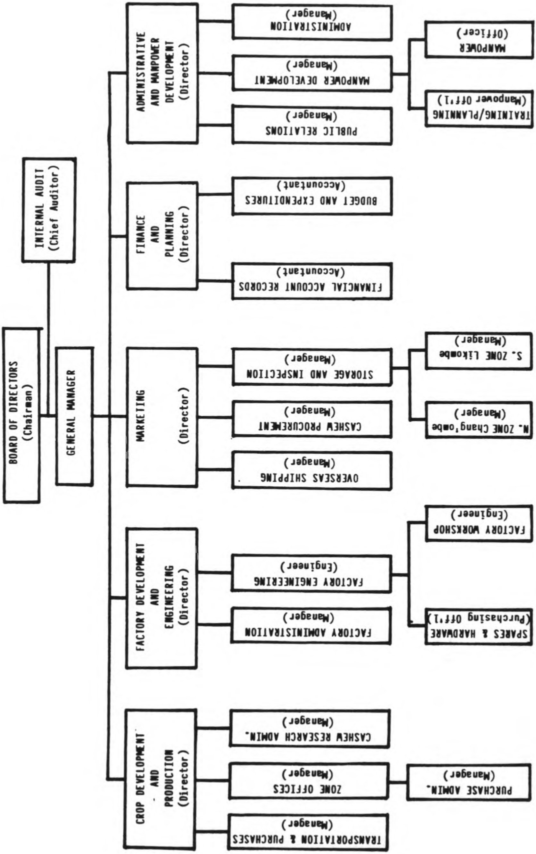
(A) Facility opening/closing strategies and shipment routes found in this study should be presented to the Cashewnut Authority of Tanzania for consideration.

(B) There is a need to explore the computational experience for the factory operating costs with three piecewise linear segments instead of the reported fixed charge approach.

(C) The use of similar solution techniques for agricultural machinery management problems, such as location of farm machinery workshops and machinery depots in large mechanized farms, should be explored.

(D) There is a need to explore a dynamic approach to the same cashew industry facility location-allocation problem for comparison with static solutions reported here.

(E) The LINDO package needs to provide for a range test when solving integer problems in order to provide for sensitivity of solutions to small parameter changes.


BOARD OF DIRECTORS
(Chairman)
INTERNAL AUDIT
(Chief Auditor)
GENERAL MANAGER
ADMINISTRATIVE AND MANPOWER DEVELOPMENT
(Director)
ADMINISTRATION
(Manager)
MANPOWER DEVELOPMENT
(Manager)
MANPOWER
(Officer)
TRAINING/PLANNING
(Manpower Off'l)
PUBLIC RELATIONS
(Manager)
FINANCE AND PLANNING
(Director)
BUDGET AND EXPENDITURES
(Accountant)
FINANCIAL ACCOUNT RECORDS
(Accountant)
MARKETING
(Director)
STORAGE AND INSPECTION
(Manager)
S. ZONE Likombe
(Manager)
N. ZONE Chang'ombe
(Manager)
CASHEW PROCUREMENT
(Manager)
OVERSEAS SHIPPING
(Manager)
FACTORY DEVELOPMENT AND ENGINEERING
(Director)
FACTORY ENGINEERING
(Engineer)
FACTORY WORKSHOP
(Engineer)
SPARES & HARDWARE
(Purchasing Off'l)
FACTORY ADMINISTRATION
(Manager)
CROP DEVELOPMENT AND PRODUCTION
(Director)
CASHEW RESEARCH ADMIN.
(Manager)
ZONE OFFICES
(Manager)
PURCHASE ADMIN.
(Manager)
TRANSPORTATION & PURCHASES
(Manager)

PRODUCTION CENTER MILEAGE CHART (Kilometers)

	Dar es salaam*	Tanita I**	Tanita II**	Kibaha**	Masasi**	Newala I**	Newala II**	Tunduru**	Likombe**	Mtwara**	Lindi**	Nachingwea**	Mtama**	Kilwa**	Songea	Kisarawe	Bagamoyo	Liwale	Utete	Mafia	Tanga	Mbeya	Morogoro
Songea	903	888	901	840	432	501	501	240	640	640	584	479	512	776	184	927	965	607	1,080	1,184	1,317	452	704
Kisarawe	44	39	52	87	692	760	760	884	631	631	540	676	612	348	927	80	116	804	231	167	455	871	231
Bagamoyo	82	77	90	125	730	799	799	922	669	669	578	714	650	386	965	116	140	842	269	205	493	909	269
Kibaha	53	48	61	42	701	770	770	893	640	640	549	685	621	357	840	87	125	813	240	176	368	784	144
Liwale	768	765	752	813	175	244	244	436	320	320	264	128	192	456	607	804	842	39	573	677	1,194	1,058	944
Mtama	576	573	560	621	80	80	80	240	128	128	72	64	61	264	512	612	650	192	381	485	989	964	752
Utete	195	192	180	240	461	530	530	653	413	413	309	445	381	117	1,080	231	269	573	77	104	621	1,024	384
Nachingwea	637	634	624	685	60	116	116	239	192	192	136	34	64	328	479	676	714	128	445	549	1,053	930	816
Mafia	131	128	116	176	565	634	634	757	517	517	413	549	485	221	1,184	167	205	677	104	20	557	960	320
Newala	725	722	709	776	69	40	40	261	140	140	221	116	80	413	501	760	799	244	530	634	1,138	952	901
Dar es Salaam*	5	24	24	48	640	709	709	832	580	580	488	624	560	296	888	39	77	765	192	128	416	832	192
Masasi	656	653	640	701	53	69	69	192	208	208	152	47	80	344	432	692	731	175	461	565	1,069	884	832
Tanga+	421	416	429	368	1,069	1,138	1,138	1,261	1,008	1,008	917	1,053	989	725	1,317	455	493	1,194	621	557	120	1,261	384
Tunduru	848	845	832	893	192	261	261	50	400	400	344	239	272	536	240	884	922	367	653	757	1,261	692	1,024
Mbeya	837	832	845	784	884	952	952	692	1,092	1,092	1,036	930	964	1,228	452	871	909	1,058	1,024	1,128	1,261	144	640
Kilwa	312	309	296	357	344	413	413	536	296	296	192	328	264	98	776	348	386	456	117	221	725	1,228	488
Morogoro	197	192	205	144	832	901	901	1,024	772	772	680	816	752	488	704	231	269	944	384	320	384	640	104
Lindi+	503	500	488	549	152	221	221	344	104	104	55	136	72	192	584	540	575	264	309	413	917	1,036	680
Mtwara+	595	592	580	640	208	140	140	400	48	48	104	192	128	296	640	631	669	320	413	517	1,008	1,092	772

*Current Operating Port (Dar es salaam)
**Processing Plant Locations (currently)
+Potential Ports

APPENDICES

APPENDIX A

CASHEWNUT AUTHORITY OF TANZANIA
FUNCTIONAL STRUCTURE

APPENDIX B

PRODUCTION CENTER MILEAGE CHART

APPENDIX C

FACTORY PRODUCTION COSTS: 1980-81

FACTORY PRODUCTION COSTS: 1980-81

Item Description	FACTORY SITE					
	Lindi	Kibaha	Mtama	Nachingwea	Newala	Masasi
SALES:						
Export sale of kernels	$ 675,532	$3,609,973	$2,045,198	–	–	–
Export sale of CNSL	12,932	–	–	–	–	–
Export sale cashew waste	11,982	–	–	–	–	–
Local sale kernels	4,317	3,147	653	–	100	–
Local sale cashew waste	169	4,630	1,123	–	–	–
Total:	**$ 704,842**	**$3,617,750**	**$2,046,974**	–	**$ 100**	–
COST OF PRODUCTION:**						
Rawnuts consumed	$ 568,545	$1,569,072	$ 839,462	$103,126	$ 74,460	$ 58,980
Packing material	167.087	80,000	31,443	4,996	19,469	10,049
Direct labor	181,570	280,969	203,405	21,587	8,952	123,414
Fixed factory overhead	441,066	524,594	279,030	172,566	326,604	241,768
Variable factory overhead	162,307	336,804	174,639	72,788	19,288	83,887
Cost of goods produced	1,520,575	2,791,439	1,527,979	375,063	429,485	518,098
Less stock @ 9/30/81	206,437	1,884,451	242,451	194,390	236,303	226,166
Total:	**$1,314,138**	**$ 906,988**	**$1,285,528**	**$180,673**	**$193,182**	**$291,932**
PREOPERATIONAL EXPENSE:						
Cost of production	$1,314,138	$ 906,988	$1,285,528	$180,673	$193,182	$291,932
Administrative expense	157,563	131,061	130,280	26,810	43,133	26,542
Prior Year Adjustment	35,161	–	–	83,633	1,938	2,860
Total:	**$1,506,862**	**$1,038,049***	**$1,415,808***	**$291,116**	**$238,253**	**$321,334**

*Preoperational expenses and prior year adjustments not included.

**See Appendix D for list of items included.

APPENDIX D

TYPICAL COST OF PRODUCTION ITEMS

TYPICAL COST OF PRODUCTION ITEMS

(A) PACKING MATERIALS:

Tins and Lips
Labels
Prints and Thinners
Gas
Cartons
Strapping Coils and Pins
Soldering Sticks

(B) DIRECT LABOR:

Machine and Manual Peeling Wages
Roasing, Shelling, and Shaker Wages
Grading Wages
Packing Wages
Production and Salaries and Wages

(C) FIXED FACTORY OVERHEAD AND DEPRECIATION RATES

Land and Buildings	4 %
Plant and Machinery	20 %
Factory Plant and Machinery	10 %
Motor Vehicles and Motor Cycles	33 1/3%
House, Office Furniture, and Equipment	15 %
Tarpolin and Loose Tools	50 %

(D) VARIABLE FACTORY OVERHEAD:

Miscellaneous Packing Expenses
Charcoal
Loading and Off-Loading
Housing Development Levy Expenses
Repair and Maintenance of Plant Machinery
Power and Light Expenses (Electrical)
Factory Fuel and Oils
Coconut Oil and Caustic Soda
Production Leave Pay
Drums
Cotton Waste
Factory Overtime Payments
Production Medical Expense
Fumigation Expense
Factory Loose Tool Consumption
Factory Welfare Expenses
Factory Personnel Traveling Expenses

APPENDIX E

MTWARA FACTORY PRODUCTION FIGURES: 1981-82

MTWARA FACTORY PRODUCTION FIGURES: 1981-82*

Rawnuts Processed:	2,078.92 tons	100 %
Kernel Recovery:	434,37 tons	20.89%
CNSL:	158.08 tons	7.60%

Classification: Kernel Products

Grades	Tins	Tons	%	Regional Range (%)	Price ($/kg)
W210	17	0.193	0.04	0.0- 0.2	6.60
W240	509	5.772	1.33	0.0- 0.5	6.49
W320	4,686	53.139	12.23	16.6-27.9	6.16
W450	4,545	51.541	11.87	10.1-12.5	5.94
SW	3,133	35.528	8.18	6.0- 9.0	4.42
DW I	—	—	—	4.2- 8.4	—
DWII	1,030	11.680	2.69	2.3-5.5	3.96
Subtotal	**13,920**	**157.853**	**36.34**		
Pieces	—	—	—	4,0-16.5	—
Butts	5,076	57.561	13.25	1.2-13.9	2.75
Splits	2,309	26.184	6.03	6.0-12.3	2.42
LWP	10,923	123.864	28.52	9.9-30.1	1.32
SWP	1,530	17.351	3.99	3.6- 7.8	1.10
DP	3,723	42.219	9.72	0.6-13.9	1.36
SCB	823	9.334	2.15	1.5- 3.6	2.20
Subtotal	**24,384**	**276.515**	**63.66**		
GRAND TOTAL	**38,304**	**434.367**	**100.00**		
Cashew Waste	—	62.230	2.99		

*1981-82 Annual Report. Figures based on 208 working days. Planned versus actual production was 3,120 and 2,089.921 tons, respectively.

CNSL Regional Range:	7-12%
Kernel Regional Range:	19-25%

APPENDIX F

CASHEW PRODUCTION LEVELS:

DERIVATION OF PREDICTION EQUATION USING ANALYSIS OF VARIANCE AND ORTHOGONOL POLYNOMIALS

(A) Cashew Production Yields: 1981-82 to 1973-74.

Subregion Blocks	PRODUCTION YEAR and AMOUNTS (000 tons/year)					
	1981-82	1979-80	1977-78	1975-76	1973-74	Subregion Total
Mtwara	20.95	14.93	34.27	35.19	60.38	165.72
Lindi	7.57	10.54	15.29	20.97	38.30	92.67
Ruvuma	3.98	1.94	7.62	4.74	9.70	27.98
Pwari	9.63	11.38	12.10	19.59	34.25	86.95
Dar es salaam	0.81	1.32	1.52	3.62	5.07	12.34
Tanga	1.03	1.11	0.84	2.51	3.26	8.75
Other	0.35	0.24	0.80	1.47	2.09	4.95
TOTAL	**44.32**	**41.46**	**72.44**	**88.09**	**153.05**	**339.36**
MEAN	**6.33**	**5.92**	**10.35**	**12.58**	**21.86**	

(B) Test for Nonadditivity:

The data presented in the preceding table was tested (AOV) for nonadditivity. The additivity was found to be highly significant ($P \leq 0.01$), indicating that the data require transformation. Since the ratio of variance to the square of the mean ($S_i^2/\overline{X}_i^2$) was found to be relatively constant, the appropriate transformation is logarithmic.

(C) Cashew Production - Transformed Data: Log (10x).

Subregion Blocks	PRODUCTION YEAR and AMOUNTS (000 tons/year)					SUBREGION TOTALS	
	1981-82	1979-80	1977-78	1975-76	1973/74	Y_i	$\sum_j Y_{ij}^2$
Mtwara	2.3212	2.1741	2.5349	2.5464	2.7809	12.3375	30.7580
Lindi	1.8791	2.0228	2.1844	2.3216	2.5832	10.9911	24.4571
Ruvuma	1.5999	1.2878	1.8820	1.6758	1.9868	8.4323	14.5157
Pwari	1.9836	2.0561	2.0828	2.2920	2.5347	10.9492	24.1782
Dar es salaam	0.9085	1.1206	1.1818	1.5587	1.7050	6.4746	8.8143
Tanga	1.0128	1.0453	0.9243	1.3997	1.5132	5.8953	7.2217
Other	0.5441	0.3802	0.9031	1.1673	1.3201	4.3148	4.3614
TOTAL $Y_{\cdot j}$	**10.2492**	**10.0869**	**11.6933**	**12.9615**	**14.4239**	**59.4148**	
MEAN	**1.4642**	**1.4410**	**1.6705**	**1.8516**	**2.0606**	**1.6976**	
$\sum_i Y_{ij}^2$	**17.5605**	**17.1974**	**22.1439**	**25.6868**	**31.7179**		**114.3065**

(D) Analysis of Variance.

Source	df	SS	MS	F
Subregions	6	11.10		
Production Year	4	1.94	0.485	28.53*
Error	24	0.41	0.017	
Total	**34**	**13.45**		

*Significant ($P \leq 0.01$)

(E) Partitioning Production Year Sum of Squares by Use of Orthogonal Polynomials.

Effect	PRODUCTION YEAR and TOTALS					Q	$r\Sigma c_i^2$	SS	F
	2 10.2492	4 19.0869	6 11.6933	8 12.9615	10 14.4239				
Linear	-2	-1	0	+1	+2	11.2240	7(10)	1.80	105.88*
Quadratic	+2	-1	-2	-1	+2	2.9112	7(14)	0.09	5.29*
Cubic	-1	+2	0	-2	+1	-1.5745	7(10)	0.04	2.35
Quartic	+1	-4	+6	-4	+1	2.6393	7(70)	0.01	1
Total								**1.94**	

(F) Prediction Equation.

The analysis shows significant ($P \leq 0.10$) linear and quadratic effects in the cashewnut production year. The prediction equation is given by:

$$\hat{\bar{Y}} = \bar{Y} + b_1\lambda_1\xi_1 + b_2\lambda_2\xi_2$$

where:

$$\bar{Y} = 1.6976 \text{ (from section (C))}$$

$$b_i = \frac{\Sigma(x_i - \bar{x})(Y_i - \bar{Y})}{\Sigma(x_i - \bar{x})^2} = \frac{Q}{r\Sigma c_i^2}$$

$$\text{i.e., } b_1 = \frac{11.2240}{7(10)}; \ b_2 = \frac{2.9112}{7(14)}$$

$\lambda_1, \lambda_2 = 1$, from tables of polynomials (Steel and Torrie, 1980)

and:

$$\xi_{k+1} = \xi_1\xi_k - \frac{k^2(n^2 - k^2)}{4(4k^2 - 1)}\xi_{k-1}$$

Thus:

$$\xi_1 = \frac{x_i - \bar{x}}{d} \text{ and } \xi_2 = [(\frac{x_i - \bar{x}}{d})^2 - \frac{n^2 - 1}{12}]$$

where d is spacing between consecutive x's, k is degree of polynomial, and n is the number of levels of a factor.

Therefore, the prediction equation for cashew production levels is:

$$\hat{\bar{Y}} = 1.6976 + (\frac{11.2240}{7(10)})(1)(\frac{x-6}{2}) + (\frac{2.9112}{7(14)})(1)[(\frac{x-6}{2})^2 - \frac{5^2-1}{12}]$$

$$\hat{\bar{Y}} = 1.6976 + 0.0802x - 0.4810 + 0.0297[0.25x^2 - 3x + 7]$$

$$\hat{\bar{Y}} = 1.6976 + 0.0802x - 0.4810 + 0.0074x^2 - 0.0891x + 0.2079$$

$$\hat{\bar{Y}} = 1.4245 - 0.0089x + 0.0074x^2$$

Thus, the production center transformed production level (Y) prediction equation for the ten-year production period (x = production year) is:

$$\hat{\bar{Y}} = 1.4245 - 0.0089x + 0.0074x^2$$

APPENDIX G

LAGRANGE MULTIPLIER TECHNIQUE

LAGRANGE MULTIPLIER TECHNIQUE

General Description

The Lagrange method of undetermined multipliers is designed to solve problems of the form:

Optimize $f(x_i)$ $\quad$ $i = 1,2,\ldots,n$

subject to $(x_1,x_2,\ldots,x_n)$ to satisfy the following equation:

$g_j(x_i) = b_j$ $\quad$ $i = 1,2,\ldots,n$

$j = 1,2,\ldots,m$

where $m < n$.

The general approach for the procedure begins by formulating the Lagrangean function:

$$h(x_i,\lambda_j) = f(x_i) = {}_{j=1}^{m}\lambda_j[g_j(x_i) - b_j]$$

where $\lambda_j (j=1,2,\ldots,m)$ are called <u>Lagrange</u> <u>Multipliers</u>.

The key fact should be noted that for the permissible values of $x_i (i=1,2,\ldots,n)$, $g_j(x_i)-b_j=0$ for all i, $(j=1,2,\ldots,m)$. Thus $h(x_i,\lambda_j) = f(s_i)$. Therefore, it can be shown that if $(x_i,\lambda_j) = (x_i^*,\lambda_j^*)$ is a local or global minimum or maximum for the unconstrainted function $h(x_i,\lambda_j)$, then (x_i^*) is a corresponding critical point for the original problem. The method now reduces to analyzing $h(x_i,\lambda_j)$. This involves setting the (n+m) partial derivatives at zero; that is:

$$\frac{\partial h}{\partial x_k} = \frac{\partial f}{\partial x_k} - \Sigma_{j=1}^{m} \lambda_j \frac{\partial g_i}{\partial x_k} = 0 \qquad \text{for } k = 1,2,\ldots,n$$

$$\frac{\partial h}{\partial \lambda_j} = =g_j(x_i) + b_i = 0 \qquad \text{for } i = 1,2,\ldots,m$$

and then the critical points would be obtained by solving these equations for $(x_1,x_2,\ldots,x_n;\lambda_1,\lambda_2,\ldots,\lambda_m)$. Notice that the last m equations are equivalent to the constraints in the original problem, so only permissible solutions are considered. After further analysis to identify the global minimum or maximum of h(·), the resulting value of $(x_1,x_2,\ldots,x_n)$ is the desired solution to the original problem.

As an example, consider (Hellier and Lieberman, 1980):

$$n = 2 \text{ and } m = 1$$

The problem might be to:

$$\text{Optimize } f(x_1,x_2) = x_1^2 + x_2^2 = 1$$

subject to:

$$g(x_1,x_2) = x_1^2 + x_2^2 = 1$$

(i.e., in this case, (x_1,x_2) is restricted to be in circle of radius 1 whose center is at the origin). Therefore, in this case:

$$h(x_1,x_2) = x_1^2 + 2x_2 - \lambda[x_1^2 + x_2^2 - 1]$$

so that:

$$(1) \qquad \frac{\partial h}{\partial x_1} = 2x_1 - 2\lambda x_1 = 0$$

$$(2) \qquad \frac{\partial h}{\partial x_2} = 2 - 2\lambda x_2 = 0$$

$$(3) \qquad \frac{\partial h}{\partial \lambda} = [x_1^2 + x_2^2 - 1] = 0$$

Hence:

Equation (1) implies that $\lambda=1$ or $x_1=0$

If $\lambda=1$, Equation (2) implies that $x_2=1$, $x_1=0$

If $x_1=0$, then Equation (3) implies that $x_2=\pm 1$.

Therefore, the two critical points $(x_1,x_2) = (0,1)$ and $(0,-1)$, providing the global maximum and minimum, respectively.

APPENDIX H

PREDICTION EQUATIONS: CASHEWNUT PRODUCTS FOR EXPORT

PERCENTAGE AMOUNTS* - KERNELS, RAWNUTS, AND CNSL

(A) Prediction Equation Summary.

Prediction for	Prediction Estimate Parameters**					Prediction Equation $\hat{Y} = a + bx$	Correlation Coefficient $r^2 = b_{y \cdot x} \cdot b_{x \cdot y}$
	$\overline{Y}$	$\overline{x}$	$b_{y \cdot x}$	$b_{x \cdot y}$	a		
Rawnuts	54.15	3.5	-5.96	-0.15	75.01	$\hat{Y}=75.01-5.96x$	0.89
Kernels	35.62	3.5	7.74	0.11	8.53	$\hat{Y}= 8.53+7.74x$	0.85
CNSL	3.12	3.5	0.67	1.27	0.78	$\hat{Y}= 0.78+0.67x$	0.85

*Percentage figures are based on Table 3.4.

**Regression parameter estimates calculation example is given in (B) of this Appendix.

(B) Example of Calculations for Regression Equation Parameters: Rawnuts.

$$n = 6$$

$\Sigma x = 21$ $\qquad$ $\Sigma Y = 324.9$

$\overline{x} = 3.5$ $\qquad$ $\overline{Y} = 54.15$

$\Sigma x^2 = 91$ $\qquad$ $\Sigma Y^2 = 18305.11$

$$\Sigma xY = 1032.8$$

Therefore:

$$\hat{Y} = a + bx$$

where:

$$a = \overline{y} - b\overline{x}$$

$$b_{y \cdot x} = \frac{\Sigma xy - \Sigma x \cdot \Sigma Y/n}{\Sigma x^2 - (\Sigma x)^2/n}$$

$$b_{x \cdot y} = \frac{\Sigma xY - \Sigma x \cdot \Sigma Y/n}{\Sigma Y^2 - (\Sigma Y)^2/n}$$

$$\therefore b_{y \cdot x} = \frac{1032.8 - (21)(324.9)/6}{91 - (23)^2/6} = -5.96$$

$$a = 54.15 + 5.96(3 \cdot 5) = 75.01$$

$$\underline{\underline{\therefore \hat{Y} = 75.01 = 5.96x}}$$

$$b_{y \cdot x} = -5.96$$

$$b_{x \cdot y} = \frac{1032.8 - (21)(423.9)/6}{28305.11 - (324.9)^2/6} = -0.15$$

$$\therefore b_{y \cdot x} \cdot b_{x \cdot y} = r^2 = (-5.96)(-0.15)$$

$$\cdot r^2 = 0.89$$

APPENDIX I

FORTRAN INTERFACED SUBROUTINES

FORTRAN INTERFACED SUBROUTINES

```
C********************************************************************
C* THE FOLLOWING USER SUPPLIED SUBROUTINES WERE INTERFACED          **
C* WITH THE MAIN PROGRAM IN LINDO (LINEAR INTERRACTIVE              **
C* DESCRETE OPTIMIZER ) PACKAGE TO SOLVE CASHEW INDUSTRY            **
C* PROCESSING FACILITY LOCATION-ALLOCATION STUDY IN TANZANIA        **
C* FOR THE LINKING PROCEDURE TO THE MAIN PACKAGE LINDO              **
C* SEE THE USERS' GUIDE SPECIFIC FOR THE CDC CYBER 750               **
C* RUNNING UNDER THE MICHIGAN STATE UNIVERSITY HUSTLER SYSTEM       **
C* THIS PARTICULAR SUBROUTINE IS KEPT IN  PFN-MATGENLINDO           **
C********************************************************************

      SUBROUTINE USER
C MATRIX GENERATOR FOR FACILITY LOCATION-ALLOCATION
C PLANNING ALTERNATIVES WRITTEN BY OMARI DIHENGA
C AFTER KEPNER & SCHRAGE  JUNE,1984
      DIMENSION IRO(4), VAL(4)
      DIMENSION CAP(50), FXD(50), D(300)
      LOGICAL TRUBLE
      DIMENSION ALFANM(36)
      INTEGER ALFANM,VNAME(8)
      INTEGER BLANK
C I/O NUMBERS
      DATA INPUT/5/,LOUT/6/
C ALPHABET
      DATA ALFANM/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,
     + 1HA,1HB,1HC,1HD,1HE,1HF,1HG,1HH,1HI,1HJ,1HK,1HL,1HM,
     + 1HN,1HO,1HP,1HQ,1HR,1HS,1HT,1HU,1HV,1HW,1HX,1HY,1HZ/
      BLANK = "  "
C MAXIMUM NUMBER OF PROCESSING PLANTS
      NDIM1 = 50
C MAXIMUM NUMBER OF PRODUCTION CENTERS (CUSTOMERS)
      NDIM2 = 300
      TRUBLE = .FALSE.

50    WRITE(6,1001)
1001  FORMAT(/,'  INPUT FOR PLANT AND TRANSPORTATION PROBLEM THE',/,
     + '  NO. OF PROCESSING PLANTS AND PRODUCTION CENTERS:   ')
      READ(5,*)NP,NC
      IF(NP.GT.NDIM1)WRITE(6,2001)NDIM1
      IF(NC.GT.NDIM2)WRITE(6,2002)NDIM2
      IF(NP.LT.1)WRITE(6,2005)NP
      IF(NC.LT.1)WRITE(6,2006)NC
      IF((NP.GT.NDIM1).OR.(NC.GT.NDIM2))GO TO 50
      IF((NP.LT.1).OR.(NC.LT.1))GO TO 50
      WRITE(6,1002)
1002  FORMAT('  INPUT EACH PLANT CAPACITY, FIXED COST PAIR',/,
     + '  ONE PAIR PER LINE')
      DO 100 I = 1,NP
      WRITE(6,1003) I
1003  FORMAT(1X,I4,': ')
      READ(5,*)CAP(I),FXD(I)
 100  CONTINUE

      WRITE(6,1004)
1004  FORMAT(/,'  INPUT PRODUCTION CENTER LEVELS, ONE PER LINE')
      DO 200 I =1,NC
      WRITE(6,1005) I
1005  FORMAT(1X,I4,': ')
      READ(5,*)D(I)
 200  CONTINUE

C INITIALIZING ROWS
      CALL INIT
```

```
C GENERATE ROWS

C THE OBJECTIVE FUNCTION
C MIN SUMMATION C(I,J)*X(I,J)+SUMMATION F(I)*Y(I)
      CALL DEFROW(1,0.,IDROW,TRUBLE)

C PLANT CAPACITY ROWS
C FOR EACH I:SUMMATION OVER J:X(I,J)-Y(I)*K(I)<=0
      DO 300 I = 1,NP
      CALL DEFROW(1,0.,IDROW,TRUBLE)
 300  CONTINUE

C THE PRODUCTION CENTER LEVEL ROWS
C FOR EACH J:SUMMATION OVER I:X(I,J) =D(J)
      DO 400 I =1,NC
      CALL DEFROW(0,D(I),IDROW,TRUBLE)
 400  CONTINUE

C GENERATE THE Y VARIABLES
      VNAME(1) = ALFANM(35)
      VNAME(5) = BLANK
      VNAME(6) = BLANK
      VNAME(7) = BLANK
      VNAME(8) = BLANK
      NONZ     = 2
      IRO(1)   = 1
      DO 500 I = 1,NP
      VAL(1)   = FXD(I)
      VAL(2)   = -CAP(I)
      IRO(2)   = I+1

C SET I1,I2,I3 = 3 DIGIT OF PLANT NUMBER
      I1 = I/100
      ITEMP = I-I1*100
      I2 = ITEMP/10
      I3 = ITEMP-I2*10
      VNAME(2) = ALFANM(I1+1)
      VNAME(3) = ALFANM(I2+1)
      VNAME(4) = ALFANM(I3+1)
      CALL APPCOL(VNAME,NONZ,VAL,IRO,TRUBLE)
      ITEMP = I
      CALL SETSUB(ITEMP,1.)
 500  CONTINUE

C GENERATE THE X VARIABLES
C X(I,J) REPRESENTING THE AMOUNTS OF SHIPMENT
C FROM THE PRODUCTION CENTER J TO THE
C PROCESSING PLANT I IF THAT PROCESSING PLANT
C IS A FEASIBLE SITE
      WRITE(6,1006)
1006  FORMAT(/,'  INPUT  UNIT SHIPMENT COST,IN THE FORM',/,
    + '  I,J,C(I,J), E.G. 3,6,4.5.TERMINATE WITH 0,0,0.',/,)
      VNAME(1) = ALFANM(34)
      NONZ = 3
      IRO(1) = 1
C FOR THE ALLOWED PLANT AND FACILITY
C PAIRS START LOOPING OVER FACILITY COMBINATIONS
      INDEX = 0
 600  INDEX = INDEX1
      WRITE(6,1007)K
```

```
1007  FORMAT(1X,I4,': ')
      READ(5,*)I,J,CIJ
      IF(I.LE.0)GO TO 700
      IF(I.GT.NP)WRITE(6,2003)I
      IF(J.GT.NC)WRITE(6,2004)J
      IF(I.LT.1)WRITE(6,2007)I
      IF(J.LT.1)WRITE(6,2008)J
      IF((I.GT.NP).OR.(J.GT.NC))GO TO 600
      IF((I.LT.1).OR.(J.LT.1))GO TO 600
C SET I1,I2,I3=3 DIGIT OF PLANT NUMBER
      I1 = I/100
      ITEMP = I-I1*100
      I2 = ITEMP/10
      I3 = ITEMP-I2*10
      VNAME(2) = ALFANM(I1+1)
      VNAME(3) = ALFANM(I2+1)
      VNAME(4) = ALFANM(I3+1)
C SET I1,I2,I3,I4 = 4 DIGIT OF PRODUCTION CENTER NUMBER
      I1 = J/1000
      ITEMP = J-I1*1000
      I2 = ITEMP/100
      ITEMP2 = ITEMP-I2*100
      I3 = ITEMP2/10
      I4 = ITEMP2-I3*10
      VNAME(5) = ALFANM(I1+1)
      VNAME(6) = ALFANM(I2+1)
      VNAME(7) = ALFANM(I3+1)
      VNAME(8) = ALFANM(I4+1)
      VAL(1)   = CIJ
      VAL(2)   = 1.
      IRO(2)   = I+1
      VAL(3)   = 1.
      IRO(3)   = 1+NP+J
      CALL APPCOL(VNAME,NONZ,VAL,IRO,TRUBLE)
      GO TO 600
 700  RETURN
2001  FORMAT(/,'  NUMBER OF PLANTS EXCEEDS THE MAXIMUM ALLOWED=   ',I6)
2002  FORMAT(/,'  NUMBER OF PROD.CENTERS EXCEEDS MAX ALLOWED=   ',I6)
2003  FORMAT(/,'  PLANT NO. ',I6,'  IS TOO LARGE.(IGNORED)')
2004  FORMAT(/,'  CENTER NO.', I6,'  IS TOO LARGE.(IGNORED)')
2005  FORMAT(/,'  NUMBER OF PLANTS ',I3,'  IS LESS THAN 1.')
2006  FORMAT(/,'  NUMBER OF CENTERS ',I3,'  IS LESS THAN 1.')
2007  FORMAT(/,'  NUMBER OF PLANTS, ',I3,'  IS LESS THAN 1.(IGNORED)')
2008  FORMAT(/,'  NUMBER OF CENTERS, ',I3,'  IS LESS THAN 1.(IGNORED)')
      END


      SUBROUTINE NEWIP(ACTUAL,BOUND)
C GENERATE NEXT BENDERS CONSTRAINT FOR THE FACILITY LOCATION
C ALLOCATION PROBLEM
      COMMON /PRIVAT/M,N,F(30),C(30,30)
      DIMENSION BEN(30),Y(30)
      LOGICAL TRUBLE
C OUTPUT UNIT
      DATA OUT/6/
C LETS LOOK AT THE SOLUTION
      CALL OUTSOL
      GIANT = 10.E30
C GLOBAL WILL ACCUMULATE THE TRUE COST OF THIS SOLUTION
      GLOBAL = 0.
      DO 100 I = 1,M
```

```
      IARG = I
      CALL REPVAR(IARG,PRIMAL,DUAL)
      Y(I) = PRIMAL
C ACCUMULATE THE FIXED COSTS OF OPEN PLANTS
      GLOBAL = GLOBAL+F(I)*PRIMAL
C INITIALIZE THE BENDERS CONSTRAINT TO ZERO
      BEN(I) = 0.
100   CONTINUE
C SBCOST WILL ACCUMULATE THE SUBPROBLEM OR TRANSPORTATION COSTS
      SBCOST = 0.
      DO 300 J = 1,N
C FIND THE CLOSEST OPEN PLANT
      CIJMIN = GIANT
      DO 200 I = 1,M
      IF(Y(I) .LT..9)GO TO 200
      IF(C(I,J) .LT. CIJMIN) CIJMIN = C(I,J)
200   CONTINUE
C ACCUMULATE THE SUBPROBLEM COST
      SBCOST = SBCOST+CIJMIN
C NOW COMPUTEAND SUM OVER I THE DUAL PRICES ON THE CONSTRAINTS
C X(I,J) > Y(I)
      DO 250 I = 1,M
      DP = CIJMIN - C(I,J)
C IF OPENING OF SITE I WILL HELP CUSTOMER J THEN ADD SAVINGS
      IF(DP.GT.0.) BEN(I) = BEN(I)+DP
250   CONTINUE
300   CONTINUE
C GET ACTUAL TOTAL COST
      ACTUAL = GLOBAL+SBCOST
      WRITE(6,400)ACTUAL
400   FORMAT(/,'  TRUE COST=',F12.2,/,'  ADD THE CONSTRAINT:')
C GENERATE THE BENDERS CONSTRAINT
C DEFINE THE ROW TYPE THE RHS
      CALL DEFROW(-1,SBCOST,IRNO,TRUBLE)
C NOW PUT IN THE COEFFICIENT FOR EACH VARIABLE
      DO 500 I = 1,M
      IARG = I
      IF(BEN(I).NE.0.)CALL  INSERT(IRNO,IARG,BEN(I),TRUBLE)
      IF(TRUBLE) GO TO 9000
500   CONTINUE
C INSERT THE BOUND VARIABLE
      CALL INSERT(IRNO,M+1,1.,TRUBLE)
      IF(TRUBLE) GO TO 9000
C SHOW THE NEW CONSTRAINT
      CALL LOOK(IRNO,IRNO)
      RETURN
9000  WRITE(6,9001)
9001  FORMAT(/,1X,'  OUT OF SPACE IN NEWIP')
C ABORT SOLUTION
      ACTUAL = GIANT
      RETURN
      END
```

```
C***************************************************************
C* THE FOLLOWING SUBROUTINES ARE LINKED TO LINDO PACKAGE     **
C* FOR SOLVING THE PUBLIC SECTOR ISSUES E.G. RELAXATION      **
C* OF COSTS AS SPECIFIED BY THE RESTRICTIONS IMPOSED         **
C* BY THE MINIMUM AND MAXIMUM NUMBER OF FACILITIES ALLOWED **
C* TO BE OPEN. THE PROGRAM SOLVES THE SIMPLE FACILITY        **
C* LOCATIONAL PROBLEM USING A 'BENDERS' ALGORITHM.           **
C* THE SUBROUTINE IS LINKED TO LINDO IN PFN-BENHOPLINDO.    **
C* REQUIRED INPUTS: NO. OF FACILITIES,FIXED AND ASSIGNMENT **
C* COSTS, MINIMUM AND MAXIMUM OPEN FACILITIES ALLOWED.      **
C***************************************************************

      SUBROUTINE USER(INPROB)
C MATRIX GENERATOR FOR FACILITY LOCATION WITH BENDERS CUT
C WRITTEN BY H O DIHENGA (FROM SCHRAGE &KEPNER) JUNE,1984
      COMMON/DESDATA/M,N,F(30),C(30,50)
      DIMENSION IRO(5), VAL(5)
      LOGICAL TRUBLE
      INTEGER ALFANM(36),VNAME(8)
      INTEGER BLANK
C I/O NUMBERS
      DATA INPUT/5/,LOUT/6/
C ALPHABET
      DATA ALFANM/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,
     + 1HA,1HB,1HC,1HD,1HE,1HF,1HG,1HH,1HI,1HJ,1HK,1HL,1HM,
     + 1HN,1HO,1HP,1HQ,1HR,1HS,1HT,1HU,1HV,1HW,1HX,1HY,1HZ/
      BLANK = "  "
C MAXIMUM NUMBER OF PROCESSING PLANTS
      NDIM1 = 30
C MAXIMUM NUMBER OF PRODUCTION CENTERS (CUSTOMERS)
      NDIM2 = 50
      TRUBLE = .FALSE.

50    WRITE(6,1001)
1001  FORMAT(/,'  INPUT FOR PLANT AND TRANSPORTATION PROBLEM THE',/,
     + '  NO. OF PROCESSING PLANTS AND PRODUCTION CENTERS:   ')
      READ(5,*)M,N
      IF(M.GT.NDIM1)WRITE(6,2001)NDIM1
      IF(N.GT.NDIM2)WRITE(6,2002)NDIM2
      IF(M.LT.1)WRITE(6,2005)M
      IF(N.LT.1)WRITE(6,2006)N
      IF((M.GT.NDIM1).OR.(N.GT.NDIM2))GO TO 50
      IF((M.LT.1).OR.(N.LT.1))GO TO 50
C ENTER THE OPENING RESTRICTIONS OF FACILITIES
      WRITE(6,1000)
1000  FORMAT(/,'  INPUT MINIMUM AND MAXIMUM OPEN NO. OF PLANTS:')
      READ(5,*)FMNO,FMXO
      WRITE(6,1002)
1002  FORMAT('  INPUT EACH FACILITY FIXED COSTS:')
      DO 10 I = 1,M
      WRITE(6,90)I
  90  FORMAT(1X,I4,': ')
      READ(5,*)F(I)
  10  CONTINUE

C INITIALIZING ROWS
      CALL INIT

C GENERATE ROWS

C THE OBJECTIVE FUNCTION
C MIN SUMMATION C(I,J)*X(I,J)+SUMMATION F(I)*Y(I)
      CALL DEFROW(1,0.,IRNO,TRUBLE)
```

```
C GENERATE THE FACILITY OPENING RESTRICTIONS
      CALL DEFROW(-1,FMNO,IRNO,TRUBLE)
      CALL DEFROW(1,FMXO,IRNO,TRUBLE)

C GENERATE THE Y VARIABLES
      VNAME(1) = ALFANM(35)
      VNAME(3) = BLANK
      VNAME(4) = BLANK
      VNAME(5) = BLANK
      VNAME(6) = BLANK
      VNAME(7) = BLANK
      VNAME(8) = BLANK
      NONZ     = 3
      IRO(1)   = 1
      IRO(2)   = 2
      VAL(2)   = 1.
      IRO(3)   = 3
      VAL(3)   = 1.
      DO 500 J = 1,M
      VNAME(2) = ALFANM(J+1)
      VAL(1) = F(J)
      CALL APPCOL(VNAME,NONZ,VAL,IRO,TRUBLE)
 500  CONTINUE
      WRITE(6,1004)
1004  FORMAT(/,'  INPUT ASSIGNMENTS COSTS')
      DO 20 K = 1,M*N
      WRITE(6,80)K
  80  FORMAT(1X,I4,': ')
      READ(5,*)CIJ
  20  CONTINUE

C ADD THE Z VARIABLE
      VNAME(1) = ALFANM(36)
      VNAME(2) = NULL
      NONZ = 1
      VAL(1) = 1.
      CALL APPCOL(VNAME ,NONZ,VAL,IRO,TRUBLE)
      RETURN
2001  FORMAT(/,'  NUMBER OF PLANTS EXCEEDS THE MAXIMUM ALLOWED=   ',I6)
2002  FORMAT(/,'  NUMBER OF PROD.CENTERS EXCEEDS MAX ALLOWED=   ',I6)
2003  FORMAT(/,'  PLANT NO. ',I6,'  IS TOO LARGE.(IGNORED)')
2004  FORMAT(/,'  CENTER NO.', I6,'  IS TOO LARGE.(IGNORED)')
2005  FORMAT(/,'  NUMBER OF PLANTS ',I3,'  IS LESS THAN 1.')
2006  FORMAT(/,'  NUMBER OF CENTERS ',I3,'  IS LESS THAN 1.')
2007  FORMAT(/,'  NUMBER OF PLANTS, ',I3,'  IS LESS THAN 1.(IGNORED)')
2008  FORMAT(/,'  NUMBER OF CENTERS, ',I3,'  IS LESS THAN 1.(IGNORED)')
      END


      SUBROUTINE NEWIP(ACTUAL,BOUND)
C GENERATE NEXT BENDERS CONSTRAINT FOR THE FACILITY LOCATION
C ALLOCATION PROBLEM
      COMMON /DESDATA/M,N,F(30),C(30,50)
      DIMENSION BEN(30),Y(30)
      LOGICAL TRUBLE
C OUTPUT UNIT
      DATA OUT/6/
C LETS LOOK AT THE SOLUTION
      CALL OUTSOL
      GIANT = 10.E30
C GLOBAL WILL ACCUMULATE THE TRUE COST OF THIS SOLUTION
```

```
      GLOBAL = 0.
      DO 100 I = 1,M
      IARG = I
      CALL REPVAR(IARG,PRIMAL,DUAL)
      Y(I) = PRIMAL
C ACCUMULATE THE FIXED COSTS OF OPEN PLANTS
      GLOBAL = GLOBAL+F(I)*PRIMAL
C INITIALIZE THE BENDERS CONSTRAINT TO ZERO
      BEN(I) = 0.
100   CONTINUE
C SBCOST WILL ACCUMULATE THE SUBPROBLEM OR TRANSPORTATION COSTS
      SBCOST = 0.
      DO 300 J = 1,N
C FIND THE CLOSEST OPEN PLANT
      CIJMIN = GIANT
      DO 200 I = 1,M
      IF(Y(I) .LT..9)GO TO 200
      IF(C(I,J) .LT. CIJMIN) CIJMIN = C(I,J)
200   CONTINUE
C ACCUMULATE THE SUBPROBLEM COST
      SBCOST = SBCOST+CIJMIN
C NOW COMPUTE AND SUM OVER I THE DUAL PRICES ON THE CONSTRAINTS
C X(I,J) > Y(I)
      DO 250 I = 1,M
      DP = CIJMIN - C(I,J)
C IF OPENING OF SITE I WILL HELP CUSTOMER J THEN ADD SAVINGS
      IF(DP.GT.0.) BEN(I) = BEN(I)+DP
250   CONTINUE
300   CONTINUE
C GET ACTUAL TOTAL COST
      ACTUAL = GLOBAL+SBCOST
      WRITE(6,400)ACTUAL
400   FORMAT(/,'  TRUE COST=',F12.2)
C GENERATE THE BENDERS CONSTRAINT
C DEFINE THE ROW TYPE THE RHS
      CALL DEFROW(-1,SBCOST,IRNO,TRUBLE)
C NOW PUT IN THE COEFFICIENT FOR EACH VARIABLE
      DO 500 I = 1,M
      IARG = I
      IF(BEN(I).NE.0.)CALL INSERT(IRNO,IARG,BEN(I),TRUBLE)
      IF(TRUBLE) GO TO 9000
500   CONTINUE
C INSERT THE BOUND VARIABLE
      CALL INSERT(IRNO,M+1,1.,TRUBLE)
      IF(TRUBLE) GO TO 9000
C SHOW THE NEW CONSTRAINT
      CALL LOOK(IRNO,IRNO)
      RETURN
9000  WRITE(6,9001)
9001  FORMAT(/,1X,'  OUT OF SPACE IN NEWIP')
C ABORT SOLUTION
      ACTUAL = GIANT
      RETURN
      END
```

APPENDIX J

SAMPLE MODEL OUTPUTS

SAMPLE MODEL OUTPUTS

```
MIN      650 Y001 + 680 Y002 + 430 Y003 + 250 Y004 + 280 Y005
     + 312 Y006 + 221 Y007 + 390 Y008 + 390 Y009 + 390 Y010
     + 390 Y011 + 375 Y012 + 430 Y013 + 54.4 X0050001 + 66.9 X0060001
     + 25.2 X0110001 + 25.2 X0120001 + 21 X0090002 + 21 X0100002
     + 36.1 X0080002 + 42 X0060002 + 24.8 X0070003 + 27.8 X0080003
     + 36.1 X0090003 + 36.1 X0100003 + 42 X0060003 + 28.9 X0050004
     + 37.8 X0060004 + 54.3 X0110004 + 54.3 X0120004 + 37.8 X0050005
     + 32.1 X0060005 + 33.7 X0070005 + 41.8 X0080005 + 41.8 X0090005
     + 41.8 X0100005 + 33.7 X0060006 + 18.1 X0070006 + 31.4 X0080006
     + 60.5 X0090006 + 60.5 X0100006 + 10.2 X0060007 + 66.9 X0070007
     + 91.2 X0080007 + 127.1 X0090007 + 127.1 X0100007
     + 51.3 X0040008 + 100.2 X0050008 + 137.7 X0060008
     + 124.7 X0070009 + 100.1 X0080009 + 26.2 X0130009
     + 249.2 X0070010 + 224.9 X0080010 + 125 X0130010 + 20.5 X0010011
     + 27.2 X0020011 + 45.5 X0030011 + 25.1 X0010012 + 31.9 X0020012
     + 22.1 X0030012 + 40.2 X0010013 + 47 X0020013 + 65.2 X0030013
     + 100 X0010014 + 93.8 X0020014 + 125 X0030014 + 61.2 X0040014
     + 66.7 X0010015 + 600.5 X0020015 + 91.7 X0030015
     + 115.3 X0040015 + 12.7 X0010016 + 12.7 X0020016 + 25.2 X0030016
     + 216.5 X0010017 + 223.3 X0020017 + 191.6 X0030017
     + 377.4 X0040017 + 432.8 X0010018 + 439.6 X0020018
     + 407.9 X0030018 + 459.9 X0080018 + 100 X0010019 + 16.8 X0020019
     + 75.1 X0030019 + 254.1 X0040019
SUBJECT TO
   2)   - 12 Y001 +  X0010011 +  X0010012 +  X0010013 +  X0010014
     +  X0010015 +  X0010016 +  X0010017 +  X0010018 +  X0010019
     <=   0
   3)   - 12 Y002 +  X0020011 +  X0020012 +  X0020013 +  X0020014
     +  X0020015 +  X0020016 +  X0020017 +  X0020018 +  X0020019
     <=   0
   4)   - 10 Y003 +  X0030011 +  X0030012 +  X0030013 +  X0030014
     +  X0030015 +  X0030016 +  X0030017 +  X0030018 +  X0030019
     <=   0
   5)   - 5 Y004 +  X0040008 +  X0040014 +  X0040015 +  X0040017
     +  X0040019 <=   0
   6)   - 5 Y005 +  X0050001 +  X0050004 +  X0050005 +  X0050008 <=   0
   7)   - 5 Y006 +  X0060001 +  X0060002 +  X0060003 +  X0060004
     +  X0060005 +  X0060006 +  X0060007 +  X0060008 <=   0
   8)   - 5 Y007 +  X0070003 +  X0070005 +  X0070006 +  X0070007
     +  X0070009 +  X0070010 <=   0
   9)   - 10 Y008 +  X0080002 +  X0080003 +  X0080005 +  X0080006
     +  X0080007 +  X0080009 +  X0080010 +  X0080018 <=   0
  10)   - 10 Y009 +  X0090002 +  X0090003 +  X0090005 +  X0090006
     +  X0090007 <=   0
  11)   - 10 Y010 +  X0100002 +  X0100003 +  X0100005 +  X0100006
     +  X0100007 <=   0
  12)   - 100 Y011 +  X0110001 +  X0110004 <=   0
  13)   - 8 Y012 +  X0120001 +  X0120004 <=   0
  14)   - 10 Y013 +  X0130009 +  X0130010 <=   0
  15)      X0050001 +  X0060001 +  X0110001 +  X0120001 =    1.767
  16)      X0090002 +  X0100002 +  X0080002 +  X0060002 =    9.506
  17)      X0070003 +  X0080003 +  X0090003 +  X0100003 +  X0060003
     =    4.323
  18)      X0050004 +  X0060004 +  X0110004 +  X0120004 =    1.174
  19)      X0050005 +  X0060005 +  X0070005 +  X0080005 +  X0090005
     +  X0100005 =    3.371
  20)      X0060006 +  X0070006 +  X0080006 +  X0090006 +  X0100006
     =    0.812
  21)      X0060007 +  X0070007 +  X0080007 +  X0090007 +  X0100007
     =    0.935
  22)      X0040008 +  X0050008 +  X0060008 =    0.567
  23)      X0070009 +  X0080009 +  X0130009 =    2.092
```

```
  24)      X0070010 +  X0080010 +  X0130010 =    0.055
  25)      X0010011 +  X0020011 +  X0030011 =    4.67
  26)      X0010012 +  X0020012 +  X0030012 =    0.686
  27)      X0010013 +  X0020013 +  X0030013 =    0.469
  28)      X0010014 +  X0020014 +  X0030014 +  X0040014 =    1.077
  29)      X0010015 +  X0020015 +  X0030015 +  X0040015 =    0.293
  30)      X0010016 +  X0020016 +  X0030016 =    0.5
  31)      X0010017 +  X0020017 +  X0030017 +  X0040017 =    0.515
  32)      X0010018 +  X0020018 +  X0030018 +  X0080018 =    0.139
  33)      X0010019 +  X0020019 +  X0030019 +  X0040019 =    0.125
END
SUB      Y001        1.00
SUB      Y002        1.00
SUB      Y003        1.00
SUB      Y004        1.00
SUB      Y005        1.00
SUB      Y006        1.00
SUB      Y007        1.00
SUB      Y008        1.00
SUB      Y009        1.00
SUB      Y010        1.00
SUB      Y011        1.00
SUB      Y012        1.00
SUB      Y013        1.00


                             X X X X X X X X X X X X X X X X
                             0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
                             0 0 1 1 0 1 0 0 0 0 0 1 0 0 0 1
                             5 6 1 2 9 0 8 6 7 8 9 0 6 5 6 1
   Y Y Y Y Y Y Y Y Y Y Y Y Y 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
   0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
   0 0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
   1 2 3 4 5 6 7 8 9 0 1 2 3 1 1 1 1 2 2 2 2 3 3 3 3 3 4 4 4

   1: C C C C C C C C C C C C C B B B B B B B B B B B B B B B B
   2:-B     '     '     '     '     '     '     '     '     '
   3: '-B'  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
   4:    -A '     '     '     '     '     '     '     '     '
   5:      -5     '     '     '     '     '     '     '     '
   6: '  '  '-5'  '  '  '  '  ' 1'  '  '  '  '  '  '  '  '1 '  '
   7:       '  -5 '     '     '   1 '     '   1 '     ' 1   1
   8:       '    -5     '     '     '     '     1     '     '
   9: '  '  '  '  '-A'  '  '  '  '  '  '  ' 1'  ' 1'  '  '  '  '
  10:       '     '  -A '     '     '   1 '     '   1 '     '
  11:       '     '    -A     '     '     1     '     1     '
  12: '  '  '  '  '  '  '-B'  '  '  1  '  '  '  '  '  '  '  '  1'
  13:       '     '     '  -8 '     ' 1   '     '     '     '
  14:       '     '     '    -A     '     '     '     '     '
  15: '  '  '  '  '  '  '  '  ' 1'1 1 1'  '  '  '  '  '  '  '  '
  16:       '     '     '     '     '   1 1 1 1 '     '     '
  17:       '     '     '     '     '     '     1 1 1 1 1   '
  18: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '1 1 1'
  19:       '     '     '     '     '     '     '     '     '
  20:       '     '     '     '     '     '     '     '     '
  21: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
  22:       '     '     '     '     '     '     '     '     '
  23:       '     '     '     '     '     '     '     '     '
  24: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
  25:       '     '     '     '     '     '     '     '     '
  26:       '     '     '     '     '     '     '     '     '
```

```
27: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
28:       '     '     '     '     '     '     '     '     '
29:       '     '     '     '     '     '     '     '     '
30: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
31:       '     '     '     '     '     '     '     '     '
32:       '     '     '     '     '     '     '     '     '
33: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '


 X X X X X X X X X X X X X X X X X X X X X X X X X X X X X
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 1 0 0 1 0 0 0
 2 5 6 7 8 9 0 6 7 8 9 0 6 7 8 9 0 4 5 6 7 8 3 7 8 3 1 2 3
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1
 4 5 5 5 5 5 5 6 6 6 6 6 7 7 7 7 7 8 8 8 9 9 9 0 0 0 1 1 1

 1: B B B B B B B B B B B B B B B C C B C C C C B C C C B B B
 2:       '     '     '     '     '     '     '     '   1 '
 3: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  1  '
 4:       '     '     '     '     '     '     '     '     ' 1
 5:       '     '     '     '     '   1 '     '     '     '
 6: ' 1'  '  '  '  '  '  '  '  '  '  '  1  '  '  '  '  '  '  '
 7:     1 '     ' 1   '     1     '     ' 1   '     '     '
 8:       1     '   1 '     ' 1   '     '   1 '   1 '     '
 9: '  '  ' 1'  '  '  1  '  '  '1 '  '  '  '  1  '  1  '  '  '
10:       '   1 '     ' 1   '     1     '     '     '     '
11:       '     1     '   1 '     ' 1   '     '     '     '
12: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
13: 1     '     '     '     '     '     '     '     '     '
14:       '     '     '     '     '     '     ' 1   '   1   '
15: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
16:       '     '     '     '     '     '     '     '     '
17:       '     '     '     '     '     '     '     '     '
18: 1  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
19:   1 1 1 1 1 1     '     '     '     '     '     '     '
20:       '     ' 1 1 1 1 1 '     '     '     '     '     '
21: '  '  '  '  '  '  '  '  1 1'1 1 1'  '  '  '  '  '  '  '  '
22:       '     '     '     '     '   1 1 1   '     '     '
23:       '     '     '     '     '     '   1 1 1   '     '
24: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '1 1 1'  '  '
25:       '     '     '     '     '     '     '     '   1 1 1
26:       '     '     '     '     '     '     '     '     '
27: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
28:       '     '     '     '     '     '     '     '     '
29:       '     '     '     '     '     '     '     '     '
30: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
31:       '     '     '     '     '     '     '     '     '
32:       '     '     '     '     '     '     '     '     '
33: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '


 X X X X X X X X X X X X X X X X X X X X X X X X X X X
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 1 2 3 1 2 3 1 2 3 4 1 2 3 4 1 2 3 1 2 3 4 1 2 3 8 1 2
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 2 2 2 3 3 3 4 4 4 4 5 5 5 5 6 6 6 7 7 7 7 8 8 8 8 9 9
```

```
 1: B B B B B B B B C B B C B C B B B C C C C C C C C B B '
 2: 1     1     1     ' 1   '   1 '   1 '     1     ' 1   '
 3: ' 1'  ' 1'  ' 1'  '  '1 '  '  1  '  1  '  ' 1'  '  '1 '
 4:     1 '   1 '   1 '     1     ' 1   ' 1   '   1 '     '
 5:       '     '     1     ' 1   '     '   1 '     '     '
 6: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
 7:       '     '     '     '     '     '     '     '     '
 8:       '     '     '     '     '     '     '     '     '
 9: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  1  '  '
10:       '     '     '     '     '     '     '     '     '
11:       '     '     '     '     '     '     '     '     '
12: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
13:       '     '     '     '     '     '     '     '     '
14:       '     '     '     '     '     '     '     '     '
15: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
16:       '     '     '     '     '     '     '     '     '
17:       '     '     '     '     '     '     '     '     '
18: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
19:       '     '     '     '     '     '     '     '     '
20:       '     '     '     '     '     '     '     '     '
21: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
22:       '     '     '     '     '     '     '     '     '
23:       '     '     '     '     '     '     '     '     '
24: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
25:       '     '     '     '     '     '     '     '     '
26: 1 1 1 '     '     '     '     '     '     '     '     '
27: '  '  1 1'1 '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
28:       '     1 1 1 1     '     '     '     '     '     '
29:       '     '     ' 1 1 1 1   '     '     '     '     '
30: '  '  '  '  '  '  '  '  '  '1 1 1'  '  '  '  '  '  '  '
31:       '     '     '     '     '   1 1 1 1 '     '     '
32:       '     '     '     '     '     '     1 1 1 1     '
33: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  ' 1'1 '


X X
0 0
0 0
3 4
0 0
0 0
1 1
9 9

 1: B C MIN
 2:     <
 3: '  '<
 4: 1   <
 5:   1 <
 6: '  '<
 7:     <
 8:     <
 9: '  '<
10:     <
11:     <
12: '  '<
13:     <
14:     <
15: '  '= A
16:     = A
```

```
 17:      = A
 18: '   '= A
 19:      = A
 20:      = T
 21: '   '= T
 22:      = T
 23:      = A
 24: '   '= U
 25:      = A
 26:      = T
 27: '   '= T
 28:      = A
 29:      = T
 30: '   '= T
 31:      = T
 32:      = T
 33: 1  1'= T



   LP OPTIMUM FOUND  AT STEP    54

NEW INTEGER SOLUTION AT BRANCH     11 PIVOT    122

        OBJECTIVE FUNCTION VALUE

 1)         3324.89930

VARIABLE          VALUE           REDUCED COST
     Y001           .000000          .000000
     Y002           .000000       -19.600000
     Y003          1.000000       430.000000
     Y004           .000000       -69.000000
     Y005          1.000000       260.000000
     Y006           .000000       -28.000000
     Y007          1.000000       164.500000
     Y008           .000000        31.000000
     Y009          1.000000       390.000000
     Y010          1.000000       390.000000
     Y011           .000000     -2930.000000
     Y012           .000000          .000000
     Y013           .000000      -925.000000
 X0050001          1.767000          .000000
 X0060001           .000000        76.500000
 X0110001           .000000          .000000
 X0120001           .000000        13.675000
 X0090002          9.506000          .000000
 X0100002           .000000          .000000
 X0080002           .000000        51.000000
 X0060002           .000000        89.000000
 X0070003          1.106000          .000000
 X0080003           .000000        27.600000
 X0090003           .000000          .000000
 X0100003          3.217000          .000000
 X0060003           .000000        73.900000
 X0050004          1.174000          .000000
 X0060004           .000000        72.900000
 X0110004           .000000        54.600000
 X0120004           .000000        68.275000
 X0050005          1.492000          .000000
```

```
 X0060005           .000000         58.300000
 X0070005           .000000          3.200000
 X0080005           .000000         35.900000
 X0090005           .000000           .000000
 X0100005          1.879000           .000000
 X0060006           .000000         72.300000
 X0070006           .812000           .000000
 X0080006           .000000         37.900000
 X0090006           .000000         31.100000
 X0100006           .000000         31.100000
 X0060007           .000000           .000000
 X0070007           .935000           .000000
 X0080007           .000000         48.900000
 X0090007           .000000         48.900000
 X0100007           .000000         48.900000
 X0040008           .000000         10.900000
 X0050008           .567000           .000000
 X0060008           .000000        101.500000
 X0070009          2.092000           .000000
 X0080009           .000000           .000000
 X0130009           .000000         25.700000
 X0070010           .055000           .000000
 X0080010           .000000           .300000
 X0130010           .000000           .000000
 X0010011           .000000         29.166667
 X0020011           .000000         40.000000
 X0030011          4.670000           .000000
 X0010012           .000000         57.166667
 X0020012           .000000         68.100000
 X0030012           .686000           .000000
 X0010013           .000000         29.166667
 X0020013           .000000         40.100000
 X0030013           .469000           .000000
 X0010014           .000000         29.166667
 X0020014           .000000         27.100000
 X0030014          1.077000           .000000
 X0040014           .000000           .000000
 X0010015           .000000         29.166667
 X0020015           .000000        567.100000
 X0030015           .293000           .000000
 X0040015           .000000         87.400000
 X0010016           .000000         41.666667
 X0020016           .000000         45.800000
 X0030016           .500000           .000000
 X0010017           .000000         79.066667
 X0020017           .000000         90.000000
 X0030017           .515000           .000000
 X0040017           .000000        249.600000
 X0010018           .000000         79.066667
 X0020018           .000000         90.000000
 X0030018           .139000           .000000
 X0080018           .000000         87.900000
 X0010019           .000000         79.066667
 X0020019           .000000           .000000
 X0030019           .125000           .000000
 X0040019           .000000        242.800000

ROW               SLACK          DUAL PRICES
   2)               .000000         54.166667
   3)               .000000         58.300000
```

```
      4)            1.526000          .000000
      5)             .000000        63.800000
      6)             .000000         4.000000
      7)             .000000        68.000000
      8)             .000000        11.300000
      9)             .000000        35.900000
     10)             .494000          .000000
     11)            4.904000          .000000
     12)             .000000        33.200000
     13)             .000000        46.875000
     14)             .000000       135.500000
     15)             .000000       -58.400000
     16)             .000000       -21.000000
     17)             .000000       -36.100000
     18)             .000000       -32.900000
     19)             .000000       -41.800000
     20)             .000000       -29.400000
     21)             .000000       -78.200000
     22)             .000000      -104.200000
     23)             .000000      -136.000000
     24)             .000000      -260.500000
     25)             .000000       -45.500000
     26)             .000000       -22.100000
     27)             .000000       -65.200000
     28)             .000000      -125.000000
     29)             .000000       -91.700000
     30)             .000000       -25.200000
     31)             .000000      -191.600000
     32)             .000000      -407.900000
     33)             .000000       -75.100000

 NO. ITERATIONS=      122
  BRANCHES=    11 DETERM.= 96.000E  0

   34)      Y001 >=   0
 END
 INTEGER-VARIABLES=      13


  BOUND ON OPTIMUM:  2454.409
     ENUMERATION COMPLETE. BRANCHES=    11  PIVOTS=    122

 LAST INTEGER SOLUTION IS THE BEST FOUND
```

```
MIN     650 Y001 + 680 Y002 + 430 Y003 + 250 Y004 + 280 Y005
      + 312 Y006 + 221 Y007 + 390 Y008 + 390 Y009 + 390 Y010
      + 390 Y011 + 375 Y012 + 430 Y013 +  X0020001 +  X0020002
      +  X0020003 +  X0020004 +  X0020005 +  X0020006 +  X0020007
      +  X0020008 +  X0020009 +  X0020010 +  X0020011 +  X0020012
      +  X0020013 +  X0020014 +  X0020015 +  X0020016 +  X0020017
      +  X0020018 +  X0020019 + 54.4 X0050001 + 66.9 X0060001
      + 25.2 X0110001 + 25.2 X0120001 + 21 X0090002 + 21 X0100002
      + 36.1 X0080002 + 42 X0060002 + 24.8 X0070003 + 27.8 X0080003
      + 36.1 X0090003 + 36.1 X0100003 + 42 X0060003 + 28.9 X0050004
      + 37.8 X0060004 + 54.3 X0110004 + 54.3 X0120004 + 37.8 X0050005
      + 32.1 X0060005 + 33.7 X0070005 + 41.8 X0080005 + 41.8 X0090005
      + 41.8 X0100005 + 33.7 X0060006 + 18.1 X0070006 + 31.4 X0080006
      + 60.5 X0090006 + 60.5 X0100006 + 100.2 X0060007 + 66.9 X0070007
      + 91.2 X0080007 + 127.1 X0090007 + 127.1 X0100007
      + 51.3 X0040008 + 100.2 X0050008 + 137.7 X0060008
      + 124.7 X0070009 + 100.1 X0080009 + 26.2 X0130009
      + 249.2 X0070010 + 224.9 X0080010 + 125 X0130010 + 20.5 X0010011
      + 45.5 X0030011 + 25.1 X0010012 + 22.1 X0030012 + 40.2 X0010013
      + 65.2 X0030013 + 100 X0010014 + 125 X0030014 + 61.2 X0040014
      + 60.5 X0010015 + 91.7 X0030015 + 115.3 X0040015 + 12.7 X0010016
      + 25.2 X0030016 + 216.5 X0010017 + 191.6 X0030017
      + 377.4 X0040017 + 432.8 X0010018 + 407.9 X0030018
      + 459.9 X0080018 + 100 X0010019 + 75.1 X0030019 + 254.1 X0040019
SUBJECT TO
   2)  - 12 Y001 +  X0010011 +  X0010012 +  X0010013 +  X0010014
      +  X0010015 +  X0010016 +  X0010017 +  X0010018 +  X0010019
      <=   0
   3)  - 12 Y002 +  X0020001 +  X0020002 +  X0020003 +  X0020004
      +  X0020005 +  X0020006 +  X0020007 +  X0020008 +  X0020009
      +  X0020010 +  X0020011 +  X0020012 +  X0020013 +  X0020014
      +  X0020015 +  X0020016 +  X0020017 +  X0020018 +  X0020019
      <=   0
   4)  - 10 Y003 +  X0030011 +  X0030012 +  X0030013 +  X0030014
      +  X0030015 +  X0030016 +  X0030017 +  X0030018 +  X0030019
      <=   0
   5)  - 5 Y004 +  X0040008 +  X0040014 +  X0040015 +  X0040017
      +  X0040019 <=   0
   6)  - 5 Y005 +  X0050001 +  X0050004 +  X0050005 +  X0050008 <=   0
   7)  - 5 Y006 +  X0060001 +  X0060002 +  X0060003 +  X0060004
      +  X0060005 +  X0060006 +  X0060007 +  X0060008 <=   0
   8)  - 5 Y007 +  X0070003 +  X0070005 +  X0070006 +  X0070007
      +  X0070009 +  X0070010 <=   0
   9)  - 10 Y008 +  X0080002 +  X0080003 +  X0080005 +  X0080006
      +  X0080007 +  X0080009 +  X0080010 +  X0080018 <=   0
  10)  - 10 Y009 +  X0090002 +  X0090003 +  X0090005 +  X0090006
      +  X0090007 <=   0
  11)  - 10 Y010 +  X0100002 +  X0100003 +  X0100005 +  X0100006
      +  X0100007 <=   0
  12)  - 10 Y011 +  X0110001 +  X0110004 <=   0
  13)  - 8 Y012 +  X0120001 +  X0120004 <=   0
  14)  - 10 Y013 +  X0130009 +  X0130010 <=   0
  15)      X0020001 +  X0050001 +  X0060001 +  X0110001 +  X0120001
      =    1.767
  16)      X0020002 +  X0090002 +  X0100002 +  X0080002 +  X0060002
      =    9.506
  17)      X0020003 +  X0070003 +  X0080003 +  X0090003 +  X0100003
      +  X0060003 =    4.323
  18)      X0020004 +  X0050004 +  X0060004 +  X0110004 +  X0120004
      =    1.174
  19)      X0020005 +  X0050005 +  X0060005 +  X0070005 +  X0080005
      +  X0090005 +  X0100005 =    3.371
```

```
20)     X0020006 +  X0060006 +  X0070006 +  X0080006 +  X0090006
    +  X0100006 =   0.812
21)     X0020007 +  X0060007 +  X0070007 +  X0080007 +  X0090007
    +  X0100007 =   0.935
22)     X0020008 +  X0040008 +  X0050008 +  X0060008 =    0.567
23)     X0020009 +  X0070009 +  X0080009 +  X0130009 =    2.092
24)     X0020010 +  X0070010 +  X0080010 +  X0130010 =    0.055
25)     X0020011 +  X0010011 +  X0030011 =    4.067
26)     X0020012 +  X0010012 +  X0030012 =    0.686
27)     X0020013 +  X0010013 +  X0030013 =    0.469
28)     X0020014 +  X0010014 +  X0030014 +  X0040014 =    1.077
29)     X0020015 +  X0010015 +  X0030015 +  X0040015 =    0.293
30)     X0020016 +  X0010016 +  X0030016 =    0.5
31)     X0020017 +  X0010017 +  X0030017 +  X0040017 =    0.515
32)     X0020018 +  X0010018 +  X0030018 +  X0080018 =    0.139
33)     X0020019 +  X0010019 +  X0030019 +  X0040019 =    0.125
END
SUB     Y001        1.00
SUB     Y002        1.00
SUB     Y003        1.00
SUB     Y004        1.00
SUB     Y005        1.00
SUB     Y006        1.00
SUB     Y007        1.00
SUB     Y008        1.00
SUB     Y009        1.00
SUB     Y010        1.00
SUB     Y011        1.00
SUB     Y012        1.00
SUB     Y013        1.00
```

```
                           X X X X X X X X X X X X X X X X
                           0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
                           0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
                           2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
 Y Y Y Y Y Y Y Y Y Y Y Y Y 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1
 1 2 3 4 5 6 7 8 9 0 1 2 3 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6

 1: C C C C C C C C C C C C C 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 2:-B     '     '     '     '     '     '     '     '     '
 3: '-B'  '  '  '  '  '  '  ' 1'1 1 1'1 1 1'1 1 1'1 1 1'1 1 1'
 4:    -A '     '     '     '     '     '     '     '     '
 5:      -5     '     '     '     '     '     '     '     '
 6: '  '  '-5'  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
 7:       '  -5 '     '     '     '     '     '     '     '
 8:       '    -5     '     '     '     '     '     '     '
 9: '  '  '  '  '-A'  '  '  '  '  '  '  '  '  '  '  '  '  '
10:       '     '  -A '     '     '     '     '     '     '
11:       '     '    -A     '     '     '     '     '     '
12: '  '  '  '  '  '  '-A'  '  '  '  '  '  '  '  '  '  '  '
13:       '     '     '  -8 '     '     '     '     '     '
14:       '     '     '    -A     '     '     '     '     '
15: '  '  '  '  '  '  '  '  ' 1'  '  '  '  '  '  '  '  '  '
16:       '     '     '     '   1 '     '     '     '     '
17:       '     '     '     '     1     '     '     '     '
18: '  '  '  '  '  '  '  '  '  '  ' 1'  '  '  '  '  '  '  '
19:       '     '     '     '     '   1 '     '     '     '
20:       '     '     '     '     '     1     '     '     '
```

```
21: '  '  '  '  '  '  '  '  '  '  '  '  ' 1'  '  '  '  '  '  '
22:       '     '     '     '     '     '   1 '     '     '
23:       '     '     '     '     '     '     1     '     '
24: '  '  '  '  '  '  '  '  '  '  '  '  '  '  ' 1'  '  '  '  '
25:       '     '     '     '     '     '     '   1 '     '
26:       '     '     '     '     '     '     '     1     '
27: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  ' 1'  '  '
28:       '     '     '     '     '     '     '     '   1 '
29:       '     '     '     '     '     '     '     '     1
30: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  ' 1'
31:       '     '     '     '     '     '     '     '     '
32:       '     '     '     '     '     '     '     '     '
33: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '


 X X X X X X X X X X X X X X X X X X X X X X X X X X X X X
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 1 1 0 1 0 0 0 0 0 1 0 0 0 1 1 0 0 0 0 0 1 0 0 0
 2 2 2 5 6 1 2 9 0 8 6 7 8 9 0 6 5 6 1 2 5 6 7 8 9 0 6 7 8
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 7 8 9 1 1 1 1 2 2 2 2 3 3 3 3 3 4 4 4 4 5 5 5 5 5 5 6 6 6

 1: 1 1 1 B B B B B B B B B B B B B B B B B B B B B B B B B B
 2:       '     '     '     '     '     '     '     '     '
 3: 1 1'1 '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
 4:       '     '     '     '     '     '     '     '     '
 5:       '     '     '     '     '     '     '     '     '
 6: '  '  1  '  '  '  '  '  '  '  ' 1'  '  '1 '  '  '  '  '  '
 7:       ' 1   '     ' 1   '     1   1 '     1     '   1 '
 8:       '     '     '   1 '     '     '     ' 1   '     1
 9: '  '  '  '  '  '  1  '  1  '  '  '  '  '  '  '1 '  '  ' 1'
10:       '     ' 1   '     ' 1   '     '     '     1     '
11:       '     '   1 '     '   1 '     '     '     ' 1   '
12: '  '  '  '1 '  '  '  '  '  '  '  '  1  '  '  '  '  '  '  '
13:       '     1     '     '     '     ' 1   '     '     '
14:       '     '     '     '     '     '     '     '     '
15: '  '  1 1'1 1  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
16:       '     ' 1 1 1 1   '     '     '     '     '     '
17:       '     '     '   1 1 1 1 1     '     '     '     '
18: '  '  '  '  '  '  '  '  '  '  ' 1'1 1 1'  '  '  '  '  '  '
19:       '     '     '     '     '     '   1 1 1 1 1 1 1   '
20:       '     '     '     '     '     '     '     '   1 1 1
21: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
22:       '     '     '     '     '     '     '     '     '
23:       '     '     '     '     '     '     '     '     '
24: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
25:       '     '     '     '     '     '     '     '     '
26:       '     '     '     '     '     '     '     '     '
27: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
28:       '     '     '     '     '     '     '     '     '
29:       '     '     '     '     '     '     '     '     '
30: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
31: 1     '     '     '     '     '     '     '     '     '
32:   1   '     '     '     '     '     '     '     '     '
33: '  '1 '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '


 X X X X X X X X X X X X X X X X X X X X X X X X X X X X X
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

```
 0 1 0 0 0 0 1 0 0 0 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0
 9 0 6 7 8 9 0 4 5 6 7 8 3 7 8 3 1 3 1 3 1 3 1 3 4 1 3 4 1
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 6 6 7 7 7 7 7 8 8 8 9 9 9 0 0 0 1 1 2 2 3 3 4 4 4 5 5 5 6

 1: B B C B B C C B C C C C B C C C B B B B B B B C B B B C B
 2:       '     '     '     '     ' 1   1   1 ' 1   ' 1   ' 1
 3: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
 4:       '     '     '     '     '   1 ' 1   1   1 '   1 '
 5:       '     ' 1   '     '     '     '     '     1     1
 6: '  '  '  '  '  '1 '  '  '  '  '  '  '  '  '  '  '  '  '  '
 7:     1 '     '     1     '     '     '     '     '     '
 8:       1     '     ' 1   ' 1   '     '     '     '     '
 9: '  '  ' 1'  '  '  '  '1 '  '1 '  '  '  '  '  '  '  '  '  '
10: 1     '   1 '     '     '     '     '     '     '     '
11:   1   '     1     '     '     '     '     '     '     '
12: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
13:       '     '     '     '     '     '     '     '     '
14:       '     '     '     1     1     '     '     '     '
15: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
16:       '     '     '     '     '     '     '     '     '
17:       '     '     '     '     '     '     '     '     '
18: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
19:       '     '     '     '     '     '     '     '     '
20: 1 1   '     '     '     '     '     '     '     '     '
21: '  '1 1 1'1 1  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '
22:       '     ' 1 1 1     '     '     '     '     '     '
23:       '     '     ' 1 1 1     '     '     '     '     '
24: '  '  '  '  '  '  '  '  ' 1'1 1  '  '  '  '  '  '  '  '  '
25:       '     '     '     '     ' 1 1 '     '     '     '
26:       '     '     '     '     '     1 1   '     '     '
27: '  '  '  '  '  '  '  '  '  '  '  '  '  '1 1  '  '  '  '  '
28:       '     '     '     '     '     '     ' 1 1 1     '
29:       '     '     '     '     '     '     '     ' 1 1 1
30: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  ' 1'
31:       '     '     '     '     '     '     '     '     '
32:       '     '     '     '     '     '     '     '     '
33: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '


 X X X X X X X X X X
 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0
 3 1 3 4 1 3 8 1 3 4
 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0
 1 1 1 1 1 1 1 1 1 1
 6 7 7 7 8 8 8 9 9 9

 1: B C C C C C C B B C MIN
 2:   1   ' 1   ' 1   ' <
 3: '  '  '  '  '  '  ' <
 4: 1   1 '   1 '   1 ' <
 5:       1     '     1 <
 6: '  '  '  '  '  '  ' <
 7:       '     '     ' <
 8:       '     '     ' <
 9: '  '  '  '  1  '  ' <
10:       '     '     ' <
```

```
11:     '   '   ' <
12: ' ' ' ' ' ' ' <
13:     '   '   ' <
14:     '   '   ' <
15: ' ' ' ' ' ' ' = A
16:     '   '   ' = A
17:     '   '   ' = A
18: ' ' ' ' ' ' ' = A
19:     '   '   ' = A
20:     '   '   ' = T
21: ' ' ' ' ' ' ' = T
22:     '   '   ' = T
23:     '   '   ' = A
24: ' ' ' ' ' ' ' = U
25:     '   '   ' = A
26:     '   '   ' = T
27: ' ' ' ' ' ' ' = T
28:     '   '   ' = A
29:     '   '   ' = T
30: 1 ' ' ' ' ' ' = T
31:   1 1 1 '   ' = T
32:     ' 1 1 1 ' = T
33: ' ' ' ' ' 1'1 1 = T


    LP OPTIMUM FOUND  AT STEP    53

NEW INTEGER SOLUTION AT BRANCH     12 PIVOT    149

        OBJECTIVE FUNCTION VALUE

 1)        2413.79650

VARIABLE        VALUE          REDUCED COST
     Y001          .000000        68.000000
     Y002         1.000000       -42.400000
     Y003          .000000        39.000000
     Y004         1.000000       250.000000
     Y005          .000000       235.500000
     Y006         1.000000       312.000000
     Y007         1.000000       164.500000
     Y008          .000000       307.000000
     Y009         1.000000       390.000000
     Y010          .000000       390.000000
     Y011          .000000        30.000000
     Y012          .000000        87.000000
     Y013          .000000        80.000000
 X0020001         1.767000          .000000
 X0020002          .000000        40.200000
 X0020003          .000000        25.100000
 X0020004          .000000        23.400000
 X0020005          .000000        29.100000
 X0020006          .000000        31.800000
 X0020007          .935000          .000000
 X0020008          .000000         9.900000
 X0020009         2.092000          .000000
 X0020010          .055000          .000000
 X0020011         4.067000          .000000
 X0020012          .686000          .000000
```

```
X0020013        .469000         .000000
X0020014        .357000         .000000
X0020015        .293000         .000000
X0020016        .500000         .000000
X0020017        .515000         .000000
X0020018        .139000         .000000
X0020019        .125000         .000000
X0050001        .000000        2.100000
X0060001        .000000        5.700000
X0110001        .000000         .000000
X0120001        .000000         .000000
X0090002       9.506000         .000000
X0100002        .000000         .000000
X0080002        .000000       23.400000
X0060002        .000000       21.000000
X0070003       4.188000         .000000
X0080003        .000000         .000000
X0090003        .135000         .000000
X0100003        .000000         .000000
X0060003        .000000        5.900000
X0050004        .000000         .000000
X0060004       1.174000         .000000
X0110004        .000000       52.500000
X0120004        .000000       52.500000
X0050005        .000000       14.600000
X0060005       3.371000         .000000
X0070005        .000000       12.900000
X0080005        .000000       18.000000
X0090005        .000000        9.700000
X0100005        .000000        9.700000
X0060006        .000000        4.300000
X0070006        .812000         .000000
X0080006        .000000       10.300000
X0090006        .000000       31.100000
X0100006        .000000       31.100000
X0060007        .000000       39.000000
X0070007        .000000       17.000000
X0080007        .000000       38.300000
X0090007        .000000       65.900000
X0100007        .000000       65.900000
X0040008        .567000         .000000
X0050008        .000000       57.800000
X0060008        .000000       86.400000
X0070009        .000000       74.800000
X0080009        .000000       47.200000
X0130009        .000000         .000000
X0070010        .000000      199.300000
X0080010        .000000      172.000000
X0130010        .000000       98.800000
X0010011        .000000        7.800000
X0030011        .000000       23.400000
X0010012        .000000       12.400000
X0030012        .000000         .000000
X0010013        .000000       27.500000
X0030013        .000000       43.100000
X0010014        .000000       87.300000
X0030014        .000000      102.900000
X0040014        .720000         .000000
X0010015        .000000       47.800000
X0030015        .000000       69.600000
X0040015        .000000       54.100000
```

APPENDIX K

SAMPLE SHIPMENT PLANS

```
 X0010016          .000000          .000000
 X0030016          .000000         3.100000
 X0010017          .000000       203.800000
 X0030017          .000000       169.500000
 X0040017          .000000       316.200000
 X0010018          .000000       420.100000
 X0030018          .000000       385.800000
 X0080018          .000000       407.000000
 X0010019          .000000        87.300000
 X0030019          .000000        53.000000
 X0040019          .000000       192.900000


ROW               SLACK         DUAL PRICES
   2)             .000000        48.500000
   3)             .000000        60.200000
   4)             .000000        39.100000
   5)            3.713000          .000000
   6)             .000000         8.900000
   7)             .455000          .000000
   8)             .000000        11.300000
   9)             .000000         8.300000
  10)             .359000          .000000
  11)             .000000          .000000
  12)             .000000        36.000000
  13)             .000000        36.000000
  14)             .000000        35.000000
  15)             .000000       -61.200000
  16)             .000000       -21.000000
  17)             .000000       -36.100000
  18)             .000000       -37.800000
  19)             .000000       -32.100000
  20)             .000000       -29.400000
  21)             .000000       -61.200000
  22)             .000000       -51.300000
  23)             .000000       -61.200000
  24)             .000000       -61.200000
  25)             .000000       -61.200000
  26)             .000000       -61.200000
  27)             .000000       -61.200000
  28)             .000000       -61.200000
  29)             .000000       -61.200000
  30)             .000000       -61.200000
  31)             .000000       -61.200000
  32)             .000000       -61.200000
  33)             .000000       -61.200000

NO. ITERATIONS=      149
 BRANCHES=   12 DETERM.=   1.000E  0

  34)      Y001 >=    0
END
INTEGER-VARIABLES=       13


 BOUND ON OPTIMUM:  1998.502
    ENUMERATION COMPLETE. BRANCHES=     12  PIVOTS=    149

LAST INTEGER SOLUTION IS THE BEST FOUND
```

```
MIN     65 Y1 + 6800 Y2 + 43 Y3 + 25 Y4 + 280 Y5 + 312 Y6 + 221 Y7
     + 390 Y8 + 390 Y9 + 390 YA + 390 YB + 375 YC + 430 YD +  Z
SUBJECT TO
   2)     Y1 +  Y2 +  Y3 +  Y4 +  Y5 +  Y6 +  Y7 +  Y8 +  Y9 +  YA +  YB
     +  YC +  YD >=   6
   3)     Y1 +  Y2 +  Y3 +  Y4 +  Y5 +  Y6 +  Y7 +  Y8 +  Y9 +  YA +  YB
     +  YC +  YD <=   13
END


      Y Y Y Y Y Y Y Y Y Y Y Y Y
      1 2 3 4 5 6 7 8 9 A B C D Z

      1: B D B B C C C C C C C C C 1 MIN
      2: 1 1 1 1 1 1 1 1 1 1 1 1 1   > 6
      3: 1 1'1 1 1'1 1 1'1 1 1'1 1   '< B



    LP OPTIMUM FOUND  AT STEP     11

LP OPTIMUM IS IP OPTIMUM


NEW INTEGER SOLUTION AT BRANCH      0 PIVOT      11

         OBJECTIVE FUNCTION VALUE

 1)          946.000000

VARIABLE          VALUE          REDUCED COST
       Y1          1.000000        -247.000000
       Y2           .000000        6488.000000
       Y3          1.000000        -269.000000
       Y4          1.000000        -287.000000
       Y5          1.000000         -32.000000
       Y6          1.000000            .000000
       Y7          1.000000         -91.000000
       Y8           .000000          78.000000
       Y9           .000000          78.000000
       YA           .000000          78.000000
       YB           .000000          78.000000
       YC           .000000          63.000000
       YD           .000000         118.000000
        Z           .000000           1.000000


ROW               SLACK           DUAL PRICES
   2)               .000000        -312.000000
   3)              7.000000            .000000

NO. ITERATIONS=       11
 BRANCHES=    0 DETERM.=  1.000E  0

   4)       Z >=   0
END
INTEGER-VARIABLES=      13


 BOUND ON OPTIMUM:  946.0000
    ENUMERATION COMPLETE. BRANCHES=     0  PIVOTS=     14
```

```
LAST INTEGER SOLUTION IS THE BEST FOUND
```

1. Shipment Plan (Amounts in Tonnes*) for Run #1.1 - 1982/83: Effects of Changes in Demand.

PLANT-FACILITY (I)			PRODUCTION CENTER (J) ($)																			
#	CAP (000)	FXD (000)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	100% OF RATED PLANT CAPACITY	REFER TO FIGURES 4.2 to 4.10																				Tanita I
2																						Tanita II
3													4,067	686	469	1,077	293	500	515	139	125	Kibaha
4																						Kilwa
5			1,767			1,704	1,592			567												Lindi
6																						Mtama
7					1,106			812	935		2,092	55										Nachingwea
8																						Masasi
9					3,217		1,779															Newala I
10				9,506																		Newala II
11																						Likombe
12																						Mtwara
13																						Tunduru
			Mtwara	Newala	Masasi	Lindi	Mtama	Nachingwea	Liwale	Kilwa	Tunduru	Songea	Kisarawe	Kibaha	Bagamoyo	Utete	Mafia	Dar es salaam	Tanga	Mbeya	Morogoro	

*For example, Masasi Center will split its production sending 1,106 tonnes of raw cashews to the Nachingwea processing factory and 3,217 tonnes to the Newala I processing plant.

2. Shipment Plan (Amounts in Tonnes) for Run #1.2 - 1983-84: Effects of Changes in Demand.

PLANT-FACILITY (I)			PRODUCTION CENTER (J) ($)																			
#	CAP (000)	FXD (000)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	100% OF RATED CAPACITY	REFER TO FIGURES 4.2 to 4.10																				Tanita I
2																						Tanita II
3													5,229	569	471		162	770	1,223	15	98	Kibaha
4										1,658						1,270						Kilwa
5																						Lindi
6																						Mtama
7					806		1,153	2,060	981													Nachingwea
8					7,243						2,654	103										Masasi
9				10,000																		Newala I
10				1,870			4,424															Newala II
11																						Likombe
12			3,448			2,727																Mtwara
																						Tunduru
			Mtwara	Newala	Masasi	Lindi	Mtama	Nachingwea	Liwale	Kilwa	Tunduru	Songea	Kisarawe	Kibaha	Bagamoyo	Utete	Mafia	Dar es salaam	Tanga	Mbeya	Morogoro	

3. Shipment Plan (Amounts in Tonnes) for Run #1.3 -1984-85: Effects of Changes in Demand.

PLANT-FACILITY (I)			PRODUCTION CENTER (J) ($)																			
#	CAP (000)	FXD (000)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	100% OF RATED CAPACITY	REFER TO FIGURES 4.2 to 4.10																				Tanita I
2																						Tanita II
3													5,391	587	486		167	794	1,376	15	101	Kibaha
4										1,710						1,310						Kilwa
5																						Lindi
6																						Mtama
7					1,142		722	2,124	1,012													Nachingwea
8					7,158						2,736	106										Masasi
9				7,268																		Newala I
10				4,971			5,029															Newala II
11																						Likombe
12			3,556			2,812																Mtwara
13																						Tunduru
			Mtwara	Newala	Masasi	Lindi	Mtama	Nachingwea	Liwale	Kilwa	Tunduru	Songea	Kisarawe	Kibaha	Bagamoyo	Utete	Mafia	Dar es salaam	Tanga	Mbeya	Morogoro	

Shipment Plan (Amounts in Tonnes) for Run #1.4 - 1985-86: Effects of Changes in Demand.

PLANT-FACILITY (I)			PRODUCTION CENTER (J) ($)																			
#	CAP (000)	FXD (000)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	100% OF RATED CAPACITY	REFER TO FIGURES 4.2 to 4.10																				Tanita I
2																						Tanita II
3													5,752	626	518		178	847	1,468	16	108	Kibaha
4										1,824						1,398						Kilwa
5																						Lindi
6																						Mtama
7					1,655			2,266	1,079													Nachingwea
8					6,968						2,919	113										Masasi
9				9,424																		Newala I
10				3,634	231		6,135															Newala II
11																						Likombe
12			3,793			3,000																Mtwara
13																						Tunduru
			Mtwara	Newala	Masasi	Lindi	Mtama	Nachingwea	Liwale	Kilwa	Tunduru	Songea	Kisarawe	Kibaha	Bagamoyo	Utete	Mafia	Dar es salaam	Tanga	Mbeya	Morogoro	

5. Shipment Plan (Amounts in Tonnes) for Run #1.5 - 1986-87: Effects of Changes in Demand.

PLANT-FACILITY (I)			PRODUCTION CENTER (J) ($)																			
#	CAP (000)	FXD (000)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	100% OF RATED CAPACITY	REFER TO FIGURES 4.2 to 4.10																				Tanita I
2																						Tanita II
3													6,349	691	572			935	1,453			Kibaha
4										2,013						1,543	197		167		119	Kilwa
5																						Lindi
6						1,983	3,017															Mtama
7					1,407			2,502	1,191													Nachingwea
8					6,635						3,222	125										Masasi
9				8,168	1,832																	Newala I
10				6,245			3,755															Newala II
11																						Likombe
12			4,187			1,329																Mtwara
13																						Tunduru
			Mtwara	Newala	Masasi	Lindi	Mtama	Nachingwea	Liwale	Kilwa	Tunduru	Songea	Kisarawe	Kibaha	Bagamoyo	Utete	Mafia	Dar es salaam	Tanga	Mbeya	Morogoro	

6. Shipment Plan (Amounts in Tonnes) for Run #1.6 - 1987-88: Effects of Changes in Demand.

PLANT-FACILITY (I)			PRODUCTION CENTER (J) ($)																			
#	CAP (000)	FXD (000)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	100% OF RATED CAPACITY	REFER TO FIGURES 4.2 to 4.10																				Tanita I
2																						Tanita II
3													7,251	789	653			1,068		21	136	Kibaha
4																						Kilwa
5																						Lindi
6						426	4,574															Mtama
7					783			2,856	1,361													Nachingwea
8					10,000																	Masasi
9				9,621	379																	Newala I
10				6,840			3,160															Newala II
11			4,782			3,356																Likombe
12																						Mtwara
13											368	143										Tunduru
14																			1,850			Tanga
15										2,299						1,762	225					Utete
			Mtwara	Newala	Masasi	Lindi	Mtama	Nachingwea	Liwale	Kilwa	Tunduru	Songea	Kisarawe	Kibaha	Bagamoyo	Utete	Mafia	Dar es salaam	Tanga	Mbeya	Morogoro	

7. Shipment Plan (Amounts in Tonnes): Run #2.1 - Capacity Utilization (50%).

PLANT-FACILITY (I)			PRODUCTION CENTER (J) ($)																			
#	CAP (000)	FXD (000)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	50% OF RATED CAPACITY	REFER TO FIGURES 4.2 to 4.10																				Tanita I
2													4,067	686	469			500	278			Tanita II
3																						Kibaha
4										567						1,077			237		125	Kilwa
5			1,767			440											293					Lindi
6						734	1,766															Mtama
7							753	812	935													Nachingwea
8					4,323		358															Masasi
9				4,506			494															Newala I
10				5,000																		Newala II
11																						Likombe
12																						Mtwara
13											2,092	55										Tunduru
			Mtwara	Newala	Masasi	Lindi	Mtama	Nachingwea	Liwale	Kilwa	Tunduru	Songea	Kisarawe	Kibaha	Bagamoyo	Utete	Mafia	Dar es salaam	Tanga	Mbeya	Morogoro	

8. Shipment Plan (Amounts in Tonnes): Run #2.2 - Capacity Utilization (75%).

PLANT-FACILITY (I)			PRODUCTION CENTER (J) ($)																			
#	CAP (000)	FXD (000)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	75% OF RATED CAPACITY	REFER TO FIGURES 4.2 to 4.10											4,067	686	469	1,077	293	500	515	139	125	Tanita I
2																						Tanita II
3																						Kibaha
4																						Kilwa
5			1,767			1,174	1,009			567												Lindi
6																						Mtama
7																						Nachingwea
8					3,606			812	935		2,092	55										Masasi
9				4,368	717																	Newala I
10				5,138			2,362															Newala II
11																						Likombe
12																						Mtwara
13					✓																	Tunduru
			Mtwara	Newala	Masasi	Lindi	Mtama	Nachingwea	Liwale	Kilwa	Tunduru	Songea	Kisarawe	Kibaha	Bagamoyo	Utete	Mafia	Dar es salaam	Tanga	Mbeya	Morogoro	

9. Shipment Plan (Amounts in Tonnes) for Run #3.1: Forcing Tanita II into Solution.

PLANT-FACILITY (I)			PRODUCTION CENTER (J) ($)																			
#	CAP (000)	FXD (000)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	100% OF RATED CAPACITY	REFER TO FIGURES 4.2 to 4.10																				Tanita I
2			1,767						935		2,092	55	4,067	686	469	357	293	500	515	139	125	Tanita II
3																						Kibaha
4										567						720						Kilwa
5																						Lindi
6						1,174	3,371															Mtama
7					4,188			812														Nachingwea
8																						Masasi
9				9,506	135																	Newala I
10																						Newala II
11																						Likombe
12																						Mtwara
13																						Tunduru
			Mtwara	Newala	Masasi	Lindi	Mtama	Nachingwea	Liwale	Kilwa	Tunduru	Songea	Kisarawe	Kibaha	Bagamoyo	Utete	Mafia	Dar es salaam	Tanga	Mbeya	Morogoro	

10. Shipment Plan (Amounts in Tonnes) for Run #3.2: Forcing Mtwara into Solution.

PLANT-FACILITY (I)			PRODUCTION CENTER (J) ($)																			
#	CAP (000)	FXD (000)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	100% OF RATED CAPACITY	REFER TO FIGURES 4.2 to 4.10																				Tanita I
2													4,067	686	469	1,077	293	500	377		125	Tanita II
3																						Kibaha
4																						Kilwa
5						1,062	3,371			567												Lindi
6			1,767	4,865				135														Mtama
7					4,323			677														Nachingwea
8																						Masasi
9																						Newala I
10																						Newala II
11						112																Likombe
12				4,641					935		2,092	55							138	139		Mtwara
13																						Tunduru
			Mtwara	Newala	Masasi	Lindi	Mtama	Nachingwea	Liwale	Kilwa	Tunduru	Songea	Kisarawe	Kibaha	Bagamoyo	Utete	Mafia	Dar es salaam	Tanga	Mbeya	Morogoro	

11. Shipment Plan (Amounts in Tonnes) for Run #3.3: Forcing Tanita I and II into Solution.

PLANT-FACILITY (I)			PRODUCTION CENTER (J) ($)																			
#	CAP (000)	FXD (000)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1	100% OF RATED CAPACITY	REFER TO FIGURES 4.2 to 4.10			3,487				935				4,067	686	469	1,077		500	515	139	125	Tanita I
2			1,767	1,033	836	1,174	3,371	812		567	2,092	55					293					Tanita II
3																						Kibaha
4																						Kilwa
5																						Lindi
6																						Mtama
7																						Nachingwea
8																						Masasi
9																						Newala I
10				8,473																		Newala II
11																						Likombe
12																						Mtwara
13																						Tunduru
			Mtwara	Newala	Masasi	Lindi	Mtama	Nachingwea	Liwale	Kilwa	Tunduru	Songea	Kisarawe	Kibaha	Bagamoyo	Utete	Mafia	Dar es salaam	Tanga	Mbeya	Morogoro	

APPENDIX L

FACILITY LOCATION-ALLOCATION PROGRAM

User's Guide in Brief
[Specific to CDC Cyber 750, MSU Hustler System]

FACILITY LOCATION-ALLOCATION PROGRAM WITH LINDO

User's Guide*

The LINDO package is a system for solving linear, integer, and quadratic programming models using the Revised Simplex Method algorithms. In this case, one is restricted to linear programs of a distribution nature; namely, locational problems.

The facility location-allocation program makes use of the presence of a replaceable dummy subroutine USER in the LINDO package. The USER-supplied subroutine, in this case, replaces the dummy subroutine. This replacement generally requires relinking of the entire package. Once "hooked up," the user can do a variety of things such as providing a special purpose input/output procedure. Several LINDO subroutines can be called from user-supplied subroutines to communicate with LINDO.*

Data Required by Program

The facility location-allocation program can analyze the distribution system's cost and locate facilities (e.g., processing plants, machinery repair workshops, manufacturing plants, etc.) and allocate the demand points (e.g.,

---

*For details in using LINDO, see, Linus Schrange, 1981, User's Manual for LINDO, The Scientific Press.

production centers, customers, depots, etc.) to supply points and also provide shipment levels for each allocation. Total system cost is also reported. Both optimum and near optimum solutions can be obtained. By using the Bender's cut algorithm, also supplied in subroutine USER, new constraints can be added during a solution session. This allows for parametric analysis as well as budgetary relaxation of costs.

Input data required by the program include:

	Example
Number of Facilities*	Processing plants versus production centers
	Repair workshops versus farm units
Facility Capacities	Annual processing capacity (tons) versus annual production level (tons)
	Man hours skilled job versus man hours of repair
Facility Fixed Costs	$/year versus $/year
Assignment Costs	Transportation, operating costs, etc., for each facility combination.

Use of Program

The facility location-allocation programs are currently stored in permanent files (Pfn) in a compiled form as

---

*What facilities are designated supply and which are demand is irrelevant as long as consistency is maintained.

MATGEN2LINDO and BENHOPLINDO. They can both be accessed by attaching an editor work file to the permanent file and executing the work file as follows:

```
          (Log in)
     OK - attach, new, Pfn.
     OK - set core.
     L? new.
     EXEC BEGUN.15.36.57.
     LINDO (UC 30 JUNE 81)
     : user
```

Printing Output and/or Input Files

LINDO has a DIVERT command which, once given (typed), all subsequent session portions linked to LINDO will be diverted to a file until a RURT command is issued. Once out of LINDO, a dispose command can then be used to print the output. The following example session provides a guide (one only types the small letters):

```
EXEC      BEGUN.16.31.49.
LINDO (UC 30 JUNE 81)
: divert                    [DIVERTS SESSION TO FILE]
FILE NUMBER:
? 2                         [YOU HAVE SPECIFIED FILE # 2]
: user                      [YOU HAVE CALLED USER ROUTINE]
     .
     .
     .
```

```
        .
        .
        .
     LAST INTEGER SOLUTION IS THE BEST FOUND

     : rvrt                    [DIVERTS SESSION TO TERMINAL]

     : leav                    [OUT OF USER ROUTINE]

     : quit                    [UNHOOKS FROM LINDO]
        .
        .
        .
        .
        .
        .

     OK - dispose, tape 2, pr=page, elite, 1 site.

                               [NOTICE RHYMING OF FILE NUMBER
                               WITH TAPE NUMBER]

                               [OUTPUT IS PRINTED BY XEROX
                               9700 HIGH SPEED PAGE PRINTER]
```

Example Session

The following session shows input and output for analyzing the setting up of an agricultural machinery repair center system for a hypothetical developing country (see Map 1). Four out of the seven agricultural centers are potential facility centers. Relevant data have been accumulated, a summary of which is given below:

Number of agricultural centers (demanding repair jobs) = 7

Number of potential repair centers (supply repair skills) = 4

Opening restrictions: Maximum open = 4

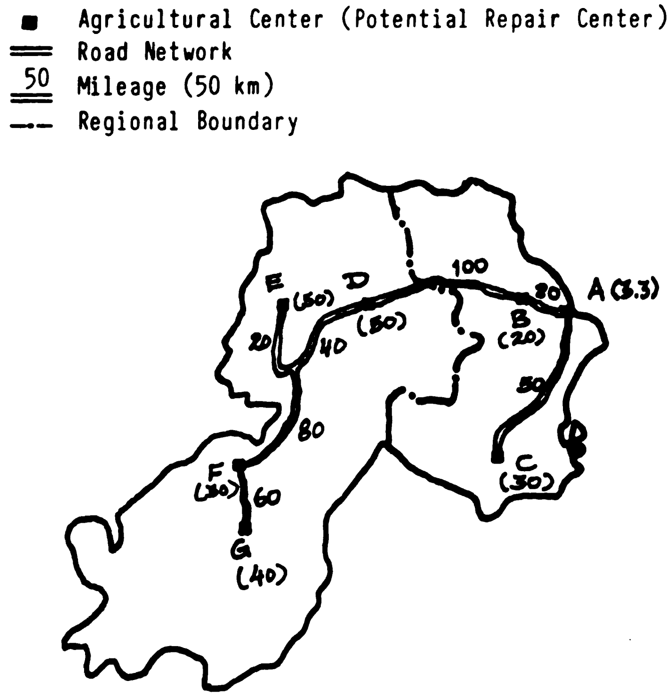
Minimum open = 2

Fixed costs/assignment costs Table 1

Table 1. Fixed and Assignment Costs.

Repair Centers		Agricultural Centers - Unit Assignment Cost*						
#	Fxd ($000)	1 A	2 B	3 C	4 D	5 E	6 F	7 G
1. A	5.0	5	30	75	180	240	360	450
2. B	3.0	30	30	105	150	210	330	420
3. D	4.0	180	150	255	75	60	180	270
4. G	2.5	450	420	525	270	240	90	60
Demand (000 Manhours/Year)		.8	1.0	1.8	1.8	1.2	2.0	.9

*Unit Assignment Costs = transportation. Estimates are $1.5 million/manhour/km return journey. Repair demands based on farm management records.



Map 1. Machinery Repair Center Hypothetical Problem: Routes and Mileage.

```
MIN     5 Y001 + 3 Y002 + 4 Y003 + 2.5 Y004 + 5 X0010001 + 30 X0020001
     + 180 X0030001 + 450 X0040001 + 30 X0010002 + 30 X0020002
     + 15 X0030002 + 420 X0040002 + 75 X0010003 + 105 X0020003
     + 255 X0030003 + 525 X0040003 + 180 X0010004 + 150 X0020004
     + 75 X0030004 + 270 X0040004 + 240 X0010005 + 210 X0020005
     + 60 X0030005 + 240 X0040005 + 360 X0010006 + 330 X0020006
     + 180 X0030006 + 90 X0040006 + 450 X0010007 + 420 X0020007
     + 270 X0030007 + 60 X0040007
SUBJECT TO
   2)  - 8 Y001 +  X0010001 +  X0010002 +  X0010003 +  X0010004
     +  X0010005 +  X0010006 +  X0010007 <=   0
   3)  - 8 Y002 +  X0020001 +  X0020002 +  X0020003 +  X0020004
     +  X0020005 +  X0020006 +  X0020007 <=   0
   4)  - 8 Y003 +  X0030001 +  X0030002 +  X0030003 +  X0030004
     +  X0030005 +  X0030006 +  X0030007 <=   0
   5)  - 8 Y004 +  X0040001 +  X0040002 +  X0040003 +  X0040004
     +  X0040005 +  X0040006 +  X0040007 <=   0
   6)     X0010001 +  X0020001 +  X0030001 +  X0040001 =    0.8
   7)     X0010002 +  X0020002 +  X0030002 +  X0040002 =    1
   8)     X0010003 +  X0020003 +  X0030003 +  X0040003 =    1.8
   9)     X0010004 +  X0020004 +  X0030004 +  X0040004 =    1.8
  10)     X0010005 +  X0020005 +  X0030005 +  X0040005 =    1.2
  11)     X0010006 +  X0020006 +  X0030006 +  X0040006 =    2
  12)     X0010007 +  X0020007 +  X0030007 +  X0040007 =    0.9
END
SUB     Y001        1.00
SUB     Y002        1.00
SUB     Y003        1.00
SUB     Y004        1.00
```

```
         X X X X X X X X X X X X X X X X X X X X X X X X X
         0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
         0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
         1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1
 Y Y Y Y 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 1 2 3 4 1 1 1 1 2 2 2 2 3 3 3 3 4 4 4 4 5 5 5 5 6 6 6 6 7

 1: 5 3 4 A 5 B C C B B B C B C C C C C B C C C B C C C C B C
 2:-8     ' 1   '   1 '     1     ' 1   '   1 '     1     ' 1
 3: '-8'  '  '1 '  '  1  '  ' 1'  '  '1 '  '  1  '  ' 1'  '  '
 4:    -8 '     1     ' 1   '   1 '     1     ' 1   '   1 '
 5:      -8     ' 1   '   1 '     1     ' 1   '   1 '     1
 6: '  '  ' 1'1 1 1'  '  '  '  '  '  '  '  '  '  '  '  '  '  '
 7:       '     '   1 1 1 1 '     '     '     '     '     '
 8:       '     '     '     1 1 1 1     '     '     '     '
 9: '  '  '  '  '  '  '  '  '  '  ' 1'1 1 1'  '  '  '  '  '  '
10:       '     '     '     '     '     '   1 1 1 1 '     '
11:       '     '     '     '     '     '     '     1 1 1 1
12: '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  '  ' 1'

 X X X
 0 0 0
 0 0 0
 2 3 4
 0 0 0
 0 0 0
 0 0 0
 7 7 7
```

```
 1: C C B MIN
 2:        <
 3: 1  '   <
 4:   1    <
 5:     1  <
 6: '  '   = T
 7:        = 1
 8:        = A
 9: '  '   = A
10:        = A
11:        = 2
12: 1 1'1  = T



    LP OPTIMUM FOUND  AT STEP     10

NEW INTEGER SOLUTION AT BRANCH       3 PIVOT      13

          OBJECTIVE FUNCTION VALUE

 1)           606.500000

VARIABLE          VALUE            REDUCED COST
     Y001        1.000000           5.000000
     Y002         .000000           3.000000
     Y003        1.000000           4.000000
     Y004        1.000000           2.500000
 X0010001         .800000            .000000
 X0020001         .000000          25.000000
 X0030001         .000000         175.000000
 X0040001         .000000         445.000000
 X0010002         .000000          15.000000
 X0020002         .000000          15.000000
 X0030002        1.000000            .000000
 X0040002         .000000         405.000000
 X0010003        1.800000            .000000
 X0020003         .000000          30.000000
 X0030003         .000000         180.000000
 X0040003         .000000         450.000000
 X0010004         .000000         105.000000
 X0020004         .000000          75.000000
 X0030004        1.800000            .000000
 X0040004         .000000         195.000000
 X0010005         .000000         180.000000
 X0020005         .000000         150.000000
 X0030005        1.200000            .000000
 X0040005         .000000         180.000000
 X0010006         .000000         270.000000
 X0020006         .000000         240.000000
 X0030006         .000000          90.000000
 X0040006        2.000000            .000000
 X0010007         .000000         390.000000
 X0020007         .000000         360.000000
 X0030007         .000000         210.000000
 X0040007         .900000            .000000


ROW               SLACK             DUAL PRICES
```

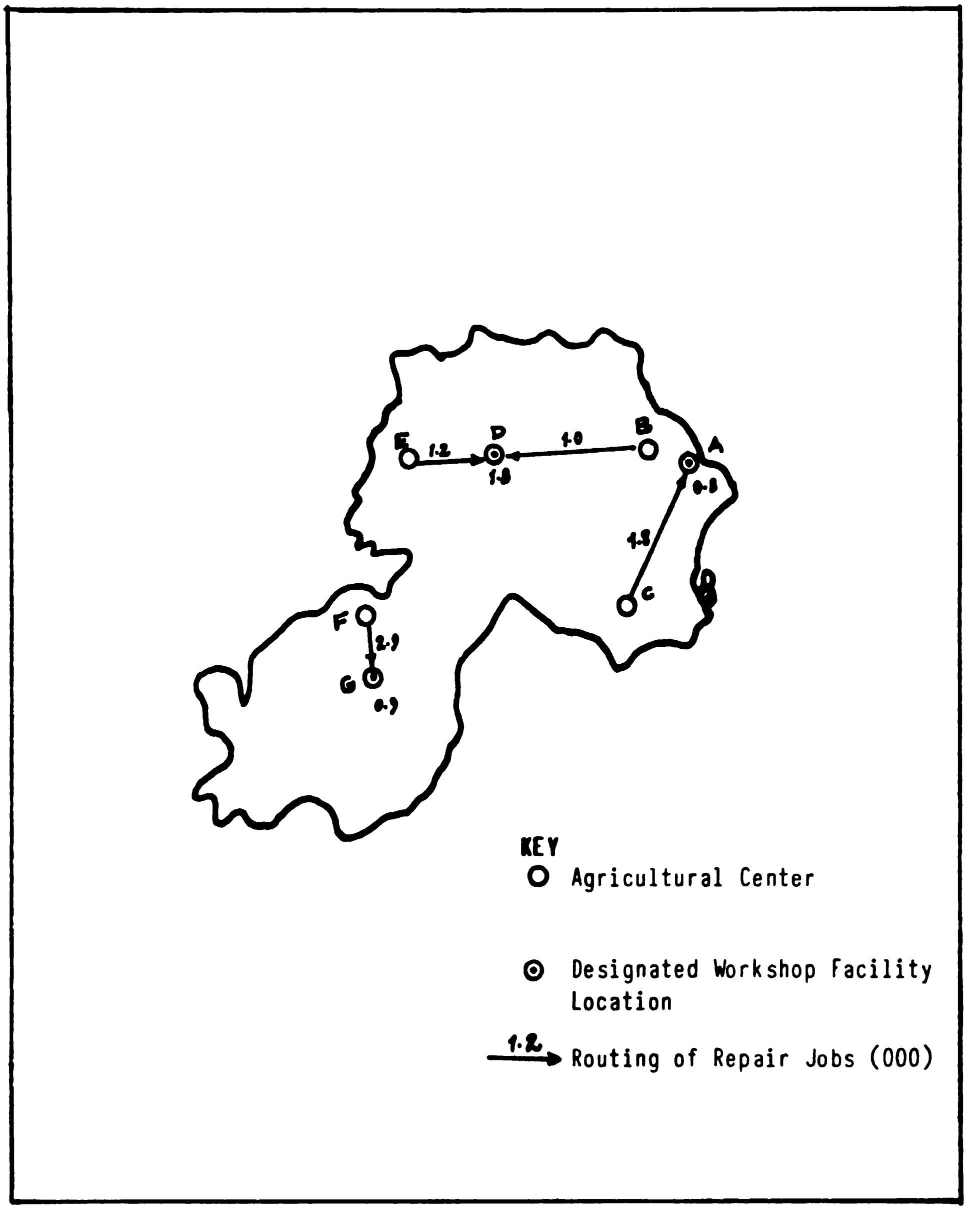
```
   2)             5.400000           .000000
   3)              .000000           .000000
   4)             4.000000           .000000
   5)             5.100000           .000000
   6)              .000000         -5.000000
   7)              .000000        -15.000000
   8)              .000000        -75.000000
   9)              .000000        -75.000000
  10)              .000000        -60.000000
  11)              .000000        -90.000000
  12)              .000000        -60.000000

NO. ITERATIONS=       13
 BRANCHES=    3 DETERM.=  1.000E  0

  13)      Y001 >=   0
END
INTEGER-VARIABLES=        4


 BOUND ON OPTIMUM:  602.9063
    ENUMERATION COMPLETE. BRANCHES=      3  PIVOTS=     13

LAST INTEGER SOLUTION IS THE BEST FOUND
```



Map 2. Machinery Unit Location Plan Showing Repair Volume Routings

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