SMALLHOLDER TEA LEAF TRANSPORTATION IN KIAMBU DISTRICT, KENYA.

By:

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Declaration

This thesis is my original work and has not been submitted for a degree in any other university.

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This thesis has been submitted with our approval as university supervisors.

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DEDICATION

To my mother Bilha Njoki whose direct and indirect support motivated me throughout the whole programme.

Abstract

Transportation problem is a major concern in Kenya's tea industry. Kenya Tea Development Authority field operation costs in general and leaf collection and transportation costs in particular have been increasing faster than growth in revenue.

This study examines transportation costs in the smallholder tea sub-sector of Kiambu district, Kenya. By using a linear programming transportation model, the study shows how these costs could be minimized to enhance the farmers' net income. Data was obtained by a survey conducted in four leaf base networks. The survey data included the number of tea buying centres, green leaf collected from each centre, distance from the centres to the factory and the fleet of vehicle serving each network. The data were used to calculate per unit cost of transporting leaf from each buying centre.

The model established an optimum pattern through which buying centres can be attached to factories such that the essential needs of each factory in terms of processing capacity are met while minimizing transportation costs.

The results indicate nearly 24 percent cost savings on green leaf transport costs when the optimal pattern rather than the existing pattern of buying centre attachment to factories is employed. The savings derived from the rearrangement in buying centre attachment provide the major economic benefit. Apart from minimizing transport costs, the new arrangement in the leaf base network also minimizes green leaf losses on transit and deterioration of quality of made tea. The re-arrangement reduces

waiting time at the farthest buying centre and eliminates the need for a second trip to such a centre on the same day. The shorter haulage distances can help to avoid partial loads and contribute towards maximum capacity of the KTDA fleet. Farmers can increase plucking since the less time spent transporting green leaf translates to more time being available for plucking.

In general, the results show that the optimal plan is associated with lower transportation costs when compared with the existing plan and triggers important responses from participants in the leaf collection operations. A reorganization of the buying centre attachment to factories is therefore necessary in order to improve on the transportation of green leaf from buying centres to factories, at least, in the study area.

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LIST OF ABBREVIATIONS

KTDA : Kenya Tea Development Authority
KTGA : Kenya Tea Growers Association
MOCD : Ministry of Co-operative Development
MOPND: Ministry of Planning and National Development
MOPW : Ministry of Public Works
NTZ : Nyayo Tea Zone
NTZDC: Nyayo Tea Zone Development Corporation
SCDA : Special Crops Development Authority

CHAPTER 1

1. INTRODUCTION

Kenya's economy relies heavily on agriculture. Substantive development has been made in this sector and significant increases have been attained in the production of major export crops including tea.

Tea is an important commodity. Currently, it ranks as the second most important foreign exchange earner, contributing more than 20 percent of the country's export earnings in 1991/92 (MOPND). The crop is grown by both large-scale and small-scale farmers. It follows, therefore, that changes in its supply and demand conditions not only affect large segments of the rural population, but also have important consequences for foreign exchange earnings and subsequent generation of public revenue.

Smallholders constitute the single most important group in both food and cash crop production. The government of Kenya has continued to emphasize the need to develop this sub-sector. As part of the rural development programmes, smallholder tea production has been encouraged and implemented in areas suitable for the crop. Development of complementary facilities such as tea roads and factories has been continuous.

In Kenya, the smallholder tea growing area is divided into eight Kenya Tea Development Authority (KTDA) zones and covers large areas of eleven districts. A total of fifteen districts are affected.

In Kiambu district, tea is grown by both large-scale and small-scale farmers. Large-scale production started in Limuru in 1903. However, the small-scale farmers were not allowed to plant tea until 1958. Currently, tea is a major cash crop for smallholder farmers in Githunguri, Gatundu and Lari divisions of the district. The large-scale tea farmers have their own management while the KTDA takes care of the small-scale tea growers.

In a span of 16 years (1958-1974), 7,006 small-scale growers in the district had planted 3,639 hectares of tea. From 1974 to date, the number of growers has risen by 128 percent while the area under tea has increased by 76 percent.

Leaf collection is an important component of the integrated services that have been offered to the smallholder tea industry by KTDA. This component has undergone major changes recently, in response to the decentralized policies that make individual factories responsible for leaf collection. Recent changes have shifted the financial responsibility for leaf inspection and collection from the KTDA to individual tea factories. From July, 1992 each factory has become directly responsible for the costs of green leaf collection and agricultural development. Leaf collection is probably KTDA'S most problematic field operations due to the high number of factories/leaf bases and the large areas covered by smallholder tea.

The cost of transporting tea leaves to the factories is of vital importance. An efficiently organised transportation system is essential so that the plucked leaf can be transported to the factory within six hours from plucking. However, KTDA faces many transport-related problems. These problems can be broadly categorized as high transport costs, loss of green leaf and lowering of tea quality.

The high transport costs can be attributed to many factors. Poor road conditions lead to high vehicle operating costs with additional costs in the form of tractor operations, and inflexibility in selection of cost effective haulage vehicles. There are two types of physical losses in green leaf namely, plucking and transit losses. Plucking losses are as a result of non-plucking when some buying centres are closed during the wet season. Transit losses occur either when collection of green leaf is delayed and the leaf loses moisture or when spillage occurs as leaf is being transported to the factories. Uncontrolled withering of green leaf during long transit delays may reduce the eventual quality of made tea. The quality of tea which is produced in any particular area determines to a large extent the success or otherwise of the tea industry.

1.1 Problem Statement

Smallholder farmers in Kenya have had no enthusiasm for growing tea on centralized blocks of land which they neither owned nor occupied (Mathare, 1978). Subsequently, it has been the policy of KTDA that small patches of tea are developed on individual holdings in order to obtain the full interest and cooperation of growers. This pattern has led to the widely scattered nature of the Authority's operations, and to increased leaf production which has strained the existing collection, transportation and processing facilities.

Smallholder tea farmers take their green leaf to leaf collection centres or buying centres, which are normally about 5 km from their farms. The green leaf has to be collected from a number of collection centres to a central factory by a fleet of vehicles. Buying centres are usually distributed along a number of main routes from the factory. Some of these centres, however, may be on spur roads off the main routes.

Green leaf transportation costs are a major expense for KTDA (KTDA Annual Report, 1983/84). They have been shown to be higher by more than 150 percent in the smallholder subsector than in the estate subsector. The main reasons are the differences in the distance involved in leaf collection and the types of leaf transport in the two sub-sectors. Because producers pay for these costs from their crop earnings, any strategy that would minimize these costs would enhance farmers' income.

In Kiambu district, tea is produced in a wide area and collected at 220 leaf buying centres. Ideally, any of the four factories in this area can be supplied with tea brought in from any of the buying centres. However, this choice is restricted because of geographical dispersion of the factories and buying centres, and the life and sensitivity of green leaf.

The amount of leaf hauled and hence the capacity utilization of leaf collection facilities is a major determinant of the level of collection costs. The criterion used to select the buying centres to serve a given factory rarely considers relative advantage in terms of distance. Consequently, the long distances involved in leaf collection result in low green leaf haulage rates that lead to lower capacity utilization rates and higher transport costs.

The increased haulage distances coupled with the inevitable loss of leaf quality in transit that occurs frustrates the efforts to reduce leaf transport costs. This has negative repercussions on producers' net income. Transport costs can be reduced if the existing road and leaf base/factory networks can be used efficiently. The initial location of KTDA factories and buying centres may have been optimal but the historical development of leaf base operations has left some buying centres assigned to inconvenient factories. This study, therefore, sets to examine an optimal pattern of attaching buying centres to factories that is commensurate with the minimization of transport costs in Kiambu district. This needed empirical analysis has not been done.

1.2 Objectives of the Study

1) To determine the transportation costs incurred in the present transport system for KTDA given the existing distribution of leaf buying centres among the factories; and
2) to establish the least cost distribution of buying centres among existing factories.

1.3 Hypotheses

The hypotheses to be tested in this study are:

1) the optimum pattern of attaching buying centres to factories does not differ from the existing pattern; and

2) the transportation costs for the optimal and existing patterns of buying centre attachment to factories are the same.

In general, this study aims at determining the optimum way of selecting the leaf buying centres that serve a given factory. This will, implicitly, lead to a reduction in transportation costs and hence an increase in the returns received by the growers. Increased payments will in turn act as an incentive to the farmers. Usually, efficient collection of green tea leaf leads to improved quality and hence premium price at auctions. Tea being a net foreign exchange earner for Kenya implies that it is imperative to optimise in all possible ways if foreign exchange earnings are to be improved.

Kenyan teas are valued for their high quality. To maintain this high standard, correct husbandry and processing practices are essential. The pattern of attaching buying centres to factories that will emerge from this study will ensure that green leaf is delivered to the factory faster, hence avoiding deterioration in quality. The auction prices of made tea reflect the quality assessments of the buyers. Local consumption of tea accounts for about 9 percent of total production. Therefore, Kenya's tea industry will continue to depend on its ability to export tea to a competitive world market. By adopting an optimal pattern of collection centre-factory combinations, KTDA will ensure that high prices of made tea are secured and that Kenya's tea competes favourably at the premium end of the market.

The whole complex of smallholder tea development under the

Authority's auspices is designed to be a self-financing entity. The KTDA is partly financed by loans raised on commercial terms and partly by self-generating revenues from cess levied on growers. The cess income also provides revenues for the redemption of loans. Therefore, a strategy that seeks to reduce transportation costs will in turn enable the Authority to finance its activities without much strain.

The rest of this thesis is organized as follows. Chapter two introduces the historical and geographical aspects of Kenya's tea industry. The third chapter deals with the literature review while chapter four focuses on the theoretical framework, data and method of data analysis. Chapter five discusses the results of the study. Finally, summary, recommendations and conclusion are presented in chapter six.

CHAPTER 2

2. KENYA'S TEA: HISTORICAL AND GEOGRAPHICAL PERSPECTIVE

2.1 Brief History of Smallholder Tea Growing in Kenya

Tea was first planted in Kenya in 1903, but before the mid-1950's it was produced entirely on estates, nearly all of which were owned by private companies. Smallholder production of tea was not encouraged prior to 1960's. There was scepticism about smallholder tea cultivation on technical and economic grounds. The economies of size were such that large and extensive plantations dominated production. Furthermore, the difficulties of organizing production, transport and collection system to meet the necessary requirements were thought to be too great to justify smallholder tea production. It was assumed that smallholders' entry into the industry would result in production of poor leaf with a consequent deterioration in the quality of tea to be marketed leading to loss of reputation and price premiums of all Kenyan teas. There were fears also on the part of the estates regarding competition for labour and the possible theft of products or even planting material. In effect, tea was among the cash crops declared illegal for small-scale farmers before 1950. Africans, meanwhile, were pressing to be allowed to grow tea because they found that the few tea bushes that were grown "illegally" grew well (Oluoch, 1978).

The Swynnerton Plan proposed that tea should be a major component of the Plan for the diversification of African agriculture (Swynnerton, 1954). The plan recommended that 4,800 hectares be planted by 1968. A potential of 28,300 hectares was perceived. However, a later study indicated that smallholder farming areas had a potential of about 600,000 hectares of land (Brown 1966) as shown in Table 2.1.

Table 2.1 <u>Potential Smallholder Tea Areas in Kenya by District</u>

District	Potential Area '000 Hectares
Kiambu	28.6
Murang'a	49.2
Nyeri	21.1
Kirinyaga	16.7
Embu	14.4
Kericho	117.7
Kisii	155.3
Nandi	84.7
Kakamega	77.6
Marakwet	2.0
All Areas	611.3

Source: Brown, 1966.

The potential land for tea growing in Kenya is limited by rainfall and temperatures to areas between 1700 and 2300 metres in altitude and to soils of pH 4.5 to 5.5. With such a vast potential and with the pilot projects which were run in Nyeri and Kericho since 1952 having been successful, there was increasing attention to smallholder tea development. The success of the pilot scheme led to the formation of the Nyanza and Rift Valley Tea Marketing Boards and the Central Province Tea Marketing Board to administer tea growing in the areas west and east of the Rift, respectively. This scheme encountered stiff opposition from the then tea experts pointing out numerous unsubstantiated constraints that would cause the scheme to fail.

The Special Crops Development Authority (SCDA) was created in 1960 to promote tea growing by African farmers and administer the tea industry. The political commitment made by the post colonial government facilitated the setting up of the Kenya Tea Development Authority (KTDA) in 1964. KTDA is a state corporation established under the Agriculture Act, section 191. It took over the smallholder tea planting programme from the Special Crops Development Authority, with the responsibility of fostering tea growing as a cash crop to African smallholder farmers in areas where such a crop did not exist hitherto. Broadly, its current functions include supervision of tea production in the smallholder sub-sector. It has exclusive control over the provision of planting materials, extension services and fertilizers, inspection and collection of green leaf from the farms, quality control, processing, and marketing of smallholder tea. Since 1964, the story of Kenya's small-scale tea development under the KTDA has been one of unprecedented success (KTDA Annual Report, 1986/87). The smallholder organisation started with 1,500 of the total 15,937 hectares planted at the end of 1960, accounting for 8 per cent. Table 2.2 indicates the growth of KTDA's share of national tealand.

Table 2.2: Hectare and Percentage of Mature Tea Planted in Kenya in Various Sectors in Different Years.

SECTOR		1945	1955	1965	1975	1985	1988
ESTATES	(Ha)	6,356	10,148	19,337	24,337	27,332	29,100
	(%)	(100)	(99.5)	(80.4)	(39.5)	(32.6)	(33.1)
SMALLHOLDERS	(Ha)	-	56	5,412	37,205	56,505	57,693
	(%)	_	(0.5)	(19.6)	(60.5)	(67.4)	(65.7)
NYAYO TEA ZONE	(Ha)	_	-	-	-	15	1000[a]
	(%)						(1.2)
TOTAL (Ha)		6,356	10,204	24,806	61,542	83,842	87,802

[a] Estimate

Source: Tea Research Foundation, 1991.

Within a brief period of time, tea area in the smallholder sub-sector has overtaken the plantation sector. Evidently, the smallholder sector is one of the largest and successful undertakings in post-independent Kenya accounting for over half of the country's annual tea production. The actual plantations are 9.4 percent of the potential smallholder plantations (Table 2.1) indicating that there is still potential for further exploitation. This creates the need for efficiency in the transport system in order to cope with the likely increases in production. Table 2.3 indicates that tea production has more than doubled in the last ten years.

Table 2.3: Tea Production in Kenya by Sub-sector(tonnes)

SECTOR	1946	1955	1965	1975	1985	1990
ESTATES	5,555	8,624	19,027	38,815	75,755	88,203
(%)	(100)	(100)	(96)	(68.4)	(51.5)	(44.8)
SMALLHOLDERS	-	-	796	17,339	71,339	107,805
(%)	-	(0.5)	(4.0)	(31.6)	(48.5)	(54.7)
NYAYO TEA ZONE	-	-	-	-	15	1,000[b]
(%)						(1.2)
TOTAL	5,555	8,624	19,823	56,154	147,109	197,008

[b] Estimate

Source: Tea Research Foundation, 1991.

Presently, smallholders in Kenya produce over 450 million kilogrammes of green leaf. This is more than half the country's tea on nearly 65,000 hectares of productive cultivation.

Smallholder tea yields in Kenya have increased to an average of about 1,600 kilogrammes of made tea per hectare, this being among the highest smallholder yields in the world (MOPW, 1992). This has been attributed to the favourable growing conditions in Kenya combined with effective smallholder services and a sound payment system. The high prices fetched by tea in the 1977/78 and 1984/85 production seasons encouraged both farmers and the government to adopt a policy of expansion and intensification of tea production. The infilling programme implemented by KTDA has also led to an increase in green leaf at all factories.

2.2 Smallholder Tea Areas in Kenya

During the 1920-1940 period, the highland areas west of the Rift Valley were the main centres of commercial tea production. After the world war, planting continued in Kericho district but it also spread to other highland areas. Between 1946 and 1960, forest areas were cleared in Nandi district and Limuru. A steady, though moderate expansion of the tea growing areas continued. From 1960's up to 1974, the smallholders' tea hectarage amounted to 34,647 or 58.9 percent of the national total. Figure 1 shows the distribution of smallholder tea growing area in Kenya. This area covers five of the eight provinces in Kenya namely Central, Eastern, Rift Valley ,Western and Nyanza provinces.

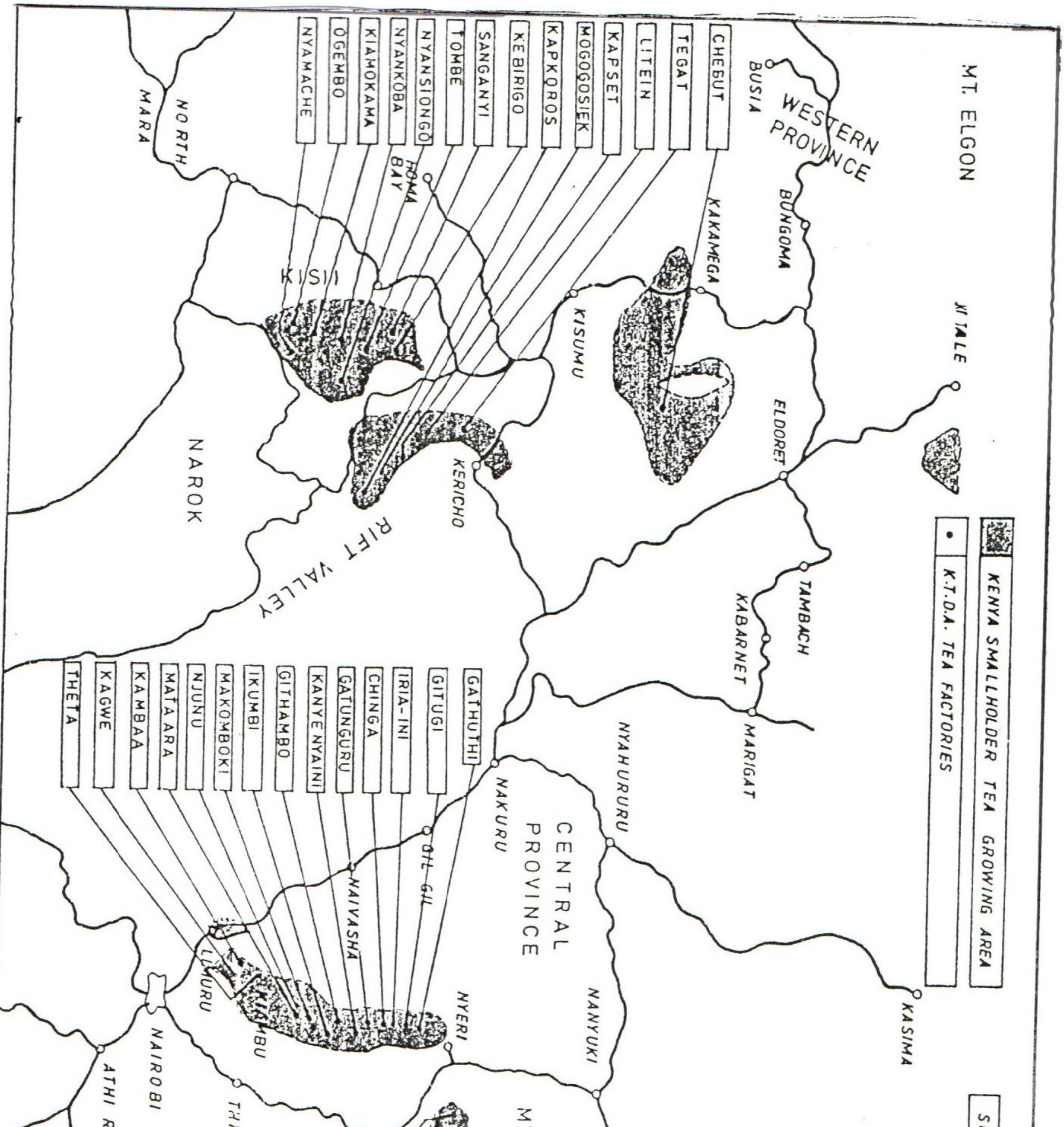

Fig 1: Smallholder Tea Areas in Kenya.

The spatial arrangement of factories and field production is rigidly determined by output-defined time constraints. The result of this is reflected in a dispersed pattern of factory and field production that gives the industry an extremely rural profile. The main determining factor here is that the green leaf has to be at the factory within six hours from plucking. If not, uncontrollable fermentation results in quality deterioration of made tea.

In Kenya, the smallholder tea growing area is divided into eight KTDA zones. A total of fifteen districts are affected. Each tea growing zone has a Superintendent in charge of leaf collection operations and workshops for vehicle maintenance. Creation of zones is done to allow for efficient administration within KTDA. Table 2.4 shows the distribution of the zones in the smallholder tea growing areas.

Table 2.4 <u>Distribution of KTDA Tea Zones</u>

Zone	Province	Districts
I	Central	Kiambu, Murang'a
II	Central	Murang'a
III	Central	Nyeri
IV	Central, Eastern	Kirinyaga, Embu
V	Eastern	Embu, Meru
VI	Rift Valley	Kericho, Nandi, Nakuru, Kakamega, Trans Nzoia
VII	Nyanza	Nyamira
VIII	Nyanza	Kisii

Source: KTDA Annual Report, 1987/88

Green leaf collection is organized around 43 leaf bases serving 39 tea factories, each of which operates 25-59 leaf buying centres. Within the eight growing zones, the leaf bases are grouped as shown in Table 2.5.

KTDA treats four of the leaf bases as special cases as these do not have factories of their own. Kakamega and Kitale bases deliver their tea to Chebut factory while Thananga delivers tea to Kieigoi. Olenguruone is a pilot project that is financed by the government and its tea is delivered to Kapkoros tea factory.

Four new factories in Murang'a (2), Kirinyaga (1), and Kericho (1) districts have been commissioned in the 1993/94 period.

Table 2.5 Smallholder Tea Production Zones and Their Leaf Bases

Zone	Leaf Bases
I	Kambaa, Kagwe, Mataara, Njunu, Theta.
II	Gatunguru, Githambo, Ikumbi, Kanyenyaini, Makomboki.
III	Chinga, Gathuthi, Gitugi, Iriaini, Ragati.
IV	Kangaita, Kimunye, Mungania, Ndima, Thumaita.
V	Githongo, Imenti, Kiegoi, Kinoro, Rukuriri, Thananga.
VI	Chebut, Kakamega, Kapkoros, Kapset, Kitale, Litein, Mogogosiek, Olenguruone, Tegat.
VII	Kebirigo, Nyansiongo, Sanganyi, Tombe.
VIII	Kiamakoma, Nyamache, Nyankoba, Ogembo.

Source: KTDA Leaf Officers' Monthly Report, 1992/93

Usually, the leaf base network is made up of a main tea collection route which is fed by smaller tea collection routes. It encompasses the whole collection network of buying centres and administrative offices. KTDA operates leaf collection networks of approximately 115 kms per leaf base. However, there are significant variations within this, with Kakamega, Kitale and Nandi district and Tegat in Kericho district having very much longer and larger networks than other leaf bases. Tea production levels vary in these tea growing zones as shown in Table 2.6.

Table 2.6 Green Leaf(GL) Production by Zones, 1992/93 Season

Zone	GL Production (million kg)
I	70.13
II	64.67
III	55.21
IV	63.23
V	61.84
VI	80.61
VII	47.08
VIII	40.34

Source: Leaf Officers Monthly Reports, 1992/93.

2.3 The Nyayo Tea Zones

Apart from KTDA, tea production in Kenya is undertaken by large private enterprises under the umbrella of the Kenya Tea Growers Association (KTGA) and the government-run estates, Nyayo Tea Zones.

KTGA is a private organization that represents the interests of commercial tea estates and medium-scale farmers at the government or trade union discussions. The Nyayo Tea Zone Development Corporation (NTZDC) was incorporated in 1986 to manage the development of a buffer zone of cultivated tea between protected forests and smallholder farming areas in Kenya. The Corporation is active in fifteen districts namely Meru, Embu, Kiambu, Murang'a, Nyeri, Kirinyaga, Narok, Nakuru, Kericho, Nandi, Bungoma, Kakamega, Kisii and the former Elgeyo Marakwet.

Currently, NTZDC has approximately 4,000 hectares of tea. The tea from these government farms is processed by KTDA factories, although the NTZDC initially was supposed to build its own factories. The effect of the Nyayo Tea Zone (NTZ) on the KTDA system is relatively small as the amount of tea delivered to KTDA leaf collection centres in 1992/93 was only 3 million kilogrammes out of a total collection of 483 million kilogrammes. Therefore, green leaf from the NTZ accounts for only a small proportion of the annual throughput of a typical KTDA factory. NTZDC is yet to have a significant impact on KTDA and the tea industry as a whole.

2.4 Leaf Collection Operations and Costs

Leaf collection is one important component of the integrated services that has been offered to the smallholder tea industry by KTDA. This component has undergone major changes recently, in response to the decentralized policies that make individual factories responsible for leaf collection.

Formerly, farmers owned the leaf inspection and buying centres while KTDA owned the factory, leaf bases, vehicles, bags and related equipment and operated these through the Leaf Collection department. The KTDA purchased all green leaf from growers and delivered it to the factories. KTDA recouped a fixed first payment from the factories and paid farmers directly, deducting a cess to cover its agricultural, green leaf inspection and collection costs. Once the individual factories announced their second payments, KTDA again paid farmers directly. This system had the inherent advantages of rewarding farmers and factories directly for made tea quality and factory management efficiency, and allowed tea factory management to devote itself entirely to the manufacturing process. Factory operating costs were covered by direct payment from tea proceeds before the second payment was announced.

Recent changes have shifted the financial responsibility for leaf inspection and collection from the KTDA to individual tea factories. From July 1992, each factory has become directly responsible for the costs of green leaf collection and agricultural development. These factory operating costs are now met from tea sales revenues. The green leaf cess which is used to fund Board operations has been reduced by 73.7 percent. The factories will also meet the agricultural extension expenses that were formerly met by KTDA head office. The KTDA Leaf Collection department will continue to manage and direct the leaf base and zone operations, and provide transport vehicles. The accounts of individual factories are debited to support these operations.

Green leaf inspection and collection costs include staff salaries and depreciation of vehicles. Transport of green leaf is the largest single direct operating cost element in the smallholder tea production process. Indirectly, the transport of green leaf affects the revenues of tea factories and KTDA through its influence on total tea production and the eventual quality of made tea that reaches the auction.

Collection costs are a function of type of leaf carriers used, amount of leaf hauled, that is, vehicle capacity utilization, distance, state of roads and overheads. A study done showed that some tea districts with low collection costs have comparatively poor bonus history (Mulinge, 1993). The study attributed the high collection costs to low capacity utilization of leaf collection facilities, and indicated that establishment of tea in marginal areas led to even higher costs and that the state of the roads is not necessarily a major constraint to achieving a high bonus.

Leaf collection is probably KTDA'S most problematic field operation due to the number of factories/leaf bases and the areas covered by smallholder tea. The rapid growth and magnitude of the operations of the Leaf Collection Department is illustrated by the data in Table 2.7.

Table 2.7: KTDA Leaf Collection Statistics:1976/77-1991/92

Year	Green Leaf Transit in million Kgs	Fleet Lorries	Fleet Tractors	Number of Factories
1976/77	129.2	177	16	24
1977/78	151.8	184	16	23
1978/79	172.1	272	15	23
1979/80	138.0	285	16	24
1980/81	145.9	275	9	27
1981/82	160.0	281	10	31
1982/83	206.2	285	12	33
1983/84	211.8	272	12	38
1984/85	283.2	272	26	39
1985/86	292.3	302	72	39
1986/87	333.2	297	73	39
1987/88	338.2	325	78	39
1988/89	428.3	306	95	39
1989/90	488.9	306	95	39
1990/91	466.4	436	120	39
1991/92	440.3	391	115	39

Source: KTDA Annual Reports, 1976/77-1991/92.

The overall growth in green leaf collected has been approximately 8 percent per annum, over the 16 years from 1976/77 to 1991/92. There are significant variations mainly as a result of changes in weather conditions during the growing season. The historic growth in KTDA transport fleet is as a result of the increase in green leaf production and number of factories.

2.5 Factory and Leaf Base Operations

The combination of field and factory-level management and operations is crucial in producing good quality tea. These operations involve collection of green leaf which is organized by the leaf bases, and processing and manufacture of made tea done at the factories.

Most factories have their own leaf base, which operates a transport fleet to collect green leaf from the buying centres. Smallholder tea farmers carry their green leaf in baskets and take it to buying centres. At the centres, leaf clerks employed by the tea factory inspect, weigh and purchase the green leaf. The leaf is then transported by leaf carriers from the buying centres to the factory. Green leaf is weighed and checked for quality again on arrival at the factory where it is then processed and packed.

2.6 Establishment of Buying Centres

The establishment of additional buying centres involves serious consideration on:

a) amount of leaf collected per buying centre;

b) amount of leaf collected per leaf collector; and

c) amount of leaf collected per kilometre.

The major criterion used is the volume of green leaf. A minimum of 75,000 kilogrammes per month for three consecutive peak months is required before an existing centre is allowed to split. Another consideration relates to distance between buying centres. New buying centres should be at least 5 km from the existing centres. The topography of the area is also taken into consideration in which case there must be evidence that features like rivers, valleys and ridges make it difficult for farmers to get to the existing buying centres.

2.7 Transport Problems in the Smallholder Sub-sector.

The transport-related problems faced by KTDA can be conveniently categorised as follows:

a) high transport costs;

b) loss of green leaf; and

c) lowering of tea quality.

High Transport Costs

The high transport costs can be attributed to many factors. Poor road conditions lead to high vehicle operating costs with additional costs in the form of tractor operations, and inflexibility in selection of cost effective haulage vehicles. Most of the KTDA's vehicles are older than the recognized "economic life" of commercial vehicles, and now require constant maintenance. In addition, many of KTDA's leaf collection operations are in areas where tea growing is scattered and leaf bases must cover large areas. This involves long distances on many leaf collection routes.

KTDA must provide carrying capacity for all green leaf so that it is capable of meeting peak demand during periods of green leaf flush. This factor and the long waiting times at the buying centres and factories mean that KTDA experiences low vehicle capacity utilization. This is also as a result of the low payload capacity of the majority of the leaf carriers. Some leaf bases are located in very rugged terrain with steep gradients of extended length. These gradients limit the use of tractors and cause major difficulties during the rains. In some cases, leaf is collected from buying centres with sub-economic throughput leading to a further increase in costs.

Loss of Green Leaf Production

There are two types of physical losses in green leaf namely, plucking and transit losses.

a) Plucking Losses

During the wet season, road conditions deteriorate so much on some tea routes that it becomes necessary for KTDA to close buying centres and organize for the green leaf to be delivered to another location. This reportedly leads to losses in green leaf production as a result of non-plucking when the centres are closed.

b) Transit Losses

These losses occur either when collection of green leaf is delayed and the leaf loses moisture or when spillage occurs as leaf is being transported to the factories. Sometimes, tea leaf is rejected at the factory when it is overheated, causing it to become "red" leaf. Transit delays can cause this problem, but so too can poor packing at the buying centres, overloading of lorries and delays in unloading at the factory. The red leaf leads to further losses.

Lowering of Tea Quality

Uncontrolled withering of green leaf during long transit delays may reduce the eventual quality of made tea. This may be a direct loss resulting from poor road conditions. Made tea quality is also affected by many other factors including insufficient transport during flush periods, and poor handling and packing of green leaf at the buying centres.

2.8 Tea Production in Kiambu District

Primary production activities which constitute on-farm and non-farm activities in the district are influenced by the degree of variation in farm types and sizes, and by the availability of formal employment.

Out of the 141,200 hectares of potential agricultural land in the district, 94,200 hectares (67 percent) fall under small-scale farms while 47,000 (33 percent) hectares are under large-scale commercial farms where mainly tea, coffee and pyrethrum are grown. Large-scale farms are owned by individuals, co-operatives and companies some of which are foreign.

In Kiambu district, tea is being grown by both large-scale and small-scale farmers. Large-scale production started in Limuru in 1903. However, the small-scale farmers were not allowed to plant tea until 1958. Currently, tea is a major cash crop for smallholder farmers in Githunguri, Gatundu and Lari divisions of the district. Large-scale tea farmers have their own management while the KTDA takes care of the small-scale tea growers.

In a span of 16 years (1958-1974), 7,006 small-scale growers had planted 3,639 hectares of tea. From 1974 to date, the number of growers has risen by 128 percent while the area under tea has increased by 76 percent. This can be explained by sub-division of land over the years causing the number of growers to increase and the average tea holding to decrease from 0.52 to 0.40 hectares. Within this period, green leaf production has increased tremendously registering a 544 percent increase. This increase in yields growth in the smallholder sub-sector occurred through increased area and improved husbandry practices. Most smallholder tea has also reached full bearing within this period, leading to increased production of green leaf.

For a long time, the tea boundaries within the district have been restricted to the area demarcated agro-ecologically as a tea zone. Between 1986 and 1991, there has been no extension in the tea boundaries except for the establishment of the Nyayo Tea Zone which stretches from north to south in the district along the forest as was scheduled. However, in 1992, a few farmers who are on marginal areas tended to extend tea growing beyond the tea boundaries. This was facilitated by poor prices for coffee. The problem is acute in Gatundu division. Good second tea payments during the last few years have also encouraged farmers to plant tea beyond the tea boundaries.

Over the years, revenue from made tea has continued to increase. Table 2.8 shows the trends of tea production in terms of output and gross revenue realised from the tea sales.

The period from 1985/86 to 1992/93 saw a 484.36 percent increase in gross revenue with an annual increase of about 60.55 percent. A notable change took place in the 1992/93 production season when revenue almost doubled due to good prices fetched by made tea and to good production achieved in the year.

Table 2.8 Green Leaf Production and Income for 1985/86-1992/93 Period

Year	Green Leaf Production (million kgs)	Gross Revenue (million Ksh)
1985/86	27.0	145.3
1986/87	32.9	179.6
1987/88	33.3	197.8
1988/89	36.3	220.7
1989/90	46.5	260.1
1990/91	42.6	365.4
1991/92	43.5	440.0
1992/93	47.7	848.9

Source: KTDA, Kiambu District Annual Report.

2.8.1 Suitability of Kiambu District for Tea Production

The distribution of tea cultivation shows that there are many factors beyond those of climate and soil that have in the past determined the distribution of the crop.

The points which have to be considered in judging the suitability of any area proposed for extensive tea development are:

a) climate, especially the amount and distribution of rainfall;

b) soil, especially as regards its depth, character of subsoil, the presence or absence of lime, and the reaction of the soil;

c) the local conditions such as the flat, hilly or broken up character of the country;

d) labour especially its amount, suitability and cost;

e) cost of transport from the farms to the processing areas and to the final market or local consuming centres; and

f) the probable quality of tea that will be produced.

Although tea is grown over a considerable geographical range, the major production areas are those that best meet the climatic and soil requirements. As regards climatic factors, best results are achieved in areas which have moderate rainfall in excess of evaporation, and which maintain stable temperatures with high humidity. There does not seem to be an upper limit to the amount of tolerable rain but less than 1750 mm annually will have impairing effects on the yields. The distribution of the precipitation over the year is obviously critical not only in tea production but also transportation. The range of temperature may be considerable but temperatures below 12-13^{0}C and over 30^{0}C can cause damage to the crop.

Tea can be grown on a wide range of soils. One main characteristic of tea is that it thrives well on acid soils. Most tea is grown on soils with a pH of between 4.0 and 6.0. A high content of aluminium has been termed another diagnostic characteristic of a good tea soil. Among other important factors that can be mentioned are the need for deep, well drained soils with good water retaining capacity.

Another physically determined constraint is the labour requirement. Tea is a very labour intensive crop. Mature tea has involved around 2,000 hours/acre/year. Labour input is heavy in the first year of planting, lighter for 2 or 3 years, the consistently heavy after plucking begins.

The cost of carrying tea to the factories is of vital importance. An efficiently organised transportation system is essential so that the plucked leaf can be transported to the factory within six hours from plucking.

The quality of tea which is produced in any particular area determines to a large extent the success or otherwise of a tea venture. High altitude areas possess natural advantage for the production of high quality teas. The effect of elevation in producing flavoury tea has been attributed to the fact that at high elevations, with their lower temperatures, the growth of tea shoots is slower than at lower elevations.

Kiambu district generally has the following characteristics:

Climate:

Climate in the district is largely influenced by altitude. Annual rainfall varies from 500 mm in the lower areas around Ruiru and increases gradually to over 1300 mm in the upper regions of Kereita forest. The rainfall regime is bimodal with long rains falling between April and May followed by a cool season during July and August, which culminates to the short rains falling in October and November. Rainfall distribution is reliable and has influenced the agricultural activities undertaken in the district to a greater extent.

Average temperatures are also influenced by altitude. For example, in the upland zone, the temperatures range from 20.4 degrees in March/April to 12.5 degrees in July/August.

Taken all together, climatic conditions in the upper part of the district are good for tea and it will grow successfully provided other factors are satisfactory.

Agro-ecological Zones and Soils

The district is divided into four broad agro-ecological zones namely, Upper Highland Zone (UHZ), Lower Highland Zone (LHZ), Upper Midland Zone (UMZ) and Lower Midland Zone (LMZ). The varied characteristics of these zones and especially the nature of the soils dictate the land use patterns in the district.

The zones which are important for tea growing in the district are UHZ and LHZ. Lari division falls in the Upper Highland Zone while Gatundu and Githunguri divisions fall in the Lower Highland Zone. The soils in most of these tea areas are eminently suitable for tea cultivation. They are moderately acidic, of moderate to high fertility, deep and well drained and this is precisely what is required for the growth of tea.

Local Conditions

The land under tea cultivation in the district consists of hills, plateaus, high level structural plains and dissected ranges. Most areas are desirable for tea cultivation.

Labour

The amount of local labour is not enough and additional labour is obtained from other districts. The hired labour is efficient since a large nucleus of the workers is permanently on or close to the tea farms where they work. Hired labour is also cheap.

Transport

Although the existing road network would bear a good deal of improvement, it seems reasonable. Mulinge (1993) noted that the tea roads in Kiambu district suffer least from heavy traffic among all the tea roads east of the Rift Valley. However, the amount of leaf hauled per kilometre needs to be improved from 41.43 to at least 60 kilogrammes per kilometre.

Probable Quality of Tea

Judged by elevation, Kiambu district can produce high quality tea. The high prices fetched by made tea manufactured in the four factories in Kiambu distict are a reflection of this tea's quality.

Therefore the nature of soils in these areas, coupled with the high altitude and the good rainfall and temperature regimes allow for successful cultivation of tea in the district.

2.8.2 Leaf Base and Factory Networks in Kiambu District

There are four leaf base/factory networks in Kiambu district all of which are in Zone 1. Each tea factory is served by a leaf base which operates a number of buying centres. The number of networks has grown over time being necessitated by the expansion of tea growing areas in the district. Table 2.9 shows the dates of commission and the number of buying centres operated by each network.

These networks serve 15,138 smallholder tea growers, received 50.4 million kilogrammes of green leaf in the 1992/93 season, and turned out 11.7 million kilogrammes of made tea. This is only 10.4 percent of the total green leaf produced in Kenya by all smallholder tea growers. Nyayo Tea Zone output is also presently being processed in these KTDA factories, although its production is low amounting to only 0.12 percent of total leaf collected by these networks.

Table 2.9: Dates of Commission and Number of Buying Centres for Networks in Kiambu district

Leaf Base/Factory Network	Date Commissioned	Number of Buying Centres
Kagwe	February 2, 1984	57
Kambaa	May 16, 1974	46
Mataara	April, 1964	58
Theta	December 30, 1980	59

Source: KTDA Annual Reports.

The four networks are served by a 484.5 km stretch of tea roads, 24.34 percent of which are bitumen surfaced roads, 40.70 percent are gravel, while 34.95 percent are earth. These roads suffer least from heavy traffic among all tea roads east of the Rift Valley. As indicated earlier, the amount of leaf hauled per kilometre is 41.43 which is below the KTDA's haulage weight target of 60 kilogrammes per kilometre. Individual leaf base networks vary considerably in size, but leaf collection operations are organized around routes, of which there are 4-8 for each leaf base. These routes have developed in accordance with the number of buying centres, quantity of green leaf usually collected, and distance to be travelled.

2.8.3 Review of the 1992/93 Tea Production Season in Kiambu District

The 1992/93 tea production season was chosen as the benchmark year in this study. This was necessitated by the fact that the number of buying centres changes from year to year. Therefore, in order to have consistent decision variables, that is, buying centre-factory combinations, it was necessary to use one season's data.

For the financial year ending in June 1992/93, the district performed well as far as green leaf production was concerned. The district managed to produce 51.8 million kilogrammes of green leaf against an estimated production of 46.04 million kilogrammes. This production earned the tea farmers Ksh. 848.9 million first and second payments inclusive as compared to Ksh. 439.96 million earned in 1991/92 season. The earnings almost doubled during the year under review. This was due to the good tea prices fetched by made tea in the markets and also due to high production achieved in the year.

Farmers continued being paid an initial payment of Ksh. 3 for every kilogramme of green leaf delivered to KTDA up to the month of June. However, as from 1st July 1992, the monthly payment was increased from Ksh.3 to Ksh.4.50 for every kilogramme of leaf delivered to the Authority.

At the end of the year, farmers were paid a second payment at the following rates per factory for every kilogramme of leaf.

Table 2.10 Second Tea Payment Rates

Factory	Rate of Payment in Ksh. 1990/91	1991/92	1992/93
Kagwe	6.68	7.50	14.35
Kambaa	6.36	7.05	12.00
Mataara	4.06	6.00	11.90
Theta	5.25	6.50	13.30

Source: KTDA, Kiambu District Annual Report.

The second payment was higher than in any other year and this is likely to encourage the growers to improve the general management of tea. Due to good second payments which have been paid to farmers during the last year, farmers are tending to plant tea beyond the tea boundaries. Growers plant tea without notifying the district tea office and thereafter legalize the tea bushes. The office has taken stern measures on tea legalization to minimize farmers going outside the tea zones.

The future of the tea industry in the district looks bright. This is attributed to good tea prices in the world market. Tea Research Foundation of Kenya is contributing in this endeavour through breeding of tea clones which are resistant to diseases and pests and which have high yields and good liquors.

The district needs to improve further. Currently the average production per bush is 0.98 kgs/bush/year while the neighbouring tea estates are now producing over 2 kgs/bush/year. With this potential, a thorough study of the transportation problems in the district is imperative.

CHAPTER 3.

3. LITERATURE REVIEW

Many scholars have looked into the transportation problems of various commodities from different angles. Overall it has been indicated that reduction in transport costs is of great importance to both the individual transporter and the society as a whole (Kohls and Downey, 1972).

Stollsteimer (1963) developed a model to determine the optimal number, size, and location of plants when transport costs from origins to plants or transport costs from plants to destinations are relevant. The study dealt with a single product case. Using a heuristic approach, Stollsteimer calculated minimum total transportation and investment costs for all possible combinations of plant sites.

Polopolus (1965) extended Stollsteimer's one product model to encompass the multiple product case. In this model aggregate assembly costs are affected by varying locational patterns as the product dimension is increased, and that total processing cost varies both with the number of plants and the combination of products handled at each optimum plant location. Both models attempted to determine the number, size, and location of plants that minimize combined transportation and processing costs.

Stollsteimer's plant location was further extended by Hurt and Tramel (1965) to transhipment plant location problem to identify location, size, and number of plants which minimize costs of assembly, processing, and distribution. They addressed themselves to some alternative formulations of a transhipment problem within the framework of the transportation model. The formulation was extended to situations involving more than one level of processing, with more than one plant at each level, and more than one final product. Miklius and Carrod (1976) gave an example of this approach, for the transport system and showed optimal transport strategies for the shipment of apples and cherries in Michigan, U.S.A. Furthermore, a heuristic iterative approach based on the Stollsteimer model was developed by Tyrchniewicz and Tosterud (1973) in their study of rail abandonment in the Boissevain region of Western Canada. Their concern was not with the location of new facilities but the impact of branch line abandonment on grain flows and handling costs. They noted that farmers in this region were incurring extra aggregate collection cost to deliver their grain to delivery points of their choice rather than the one nearest to their farms. This was a one-period analysis with one grain for one final destination.

Tyrchniewicz and Tosterud's transhipment model was further developed by Ladd and Lifferth (1975). Their study was based on monthly flows of corn and soybeans to multidestinations. The model does not minimize transportation, handling, and plant investment costs, but maximizes total net revenue (gross revenue minus transportation, handling and plant investment costs) to producers. Their concern was to optimize location, number, and size of sub-terminals in the Fort Dodge, Iowa, area. This study employed two stages of transhipment while all previous studies dealt with one stage. Generally, this type of model can include either quantity demanded at each destination or quantity supplied in each producing region.

A mixed-integer programming algorithm was developed by McCarl, Hilger and Uhrig (1977). Their objective was to optimize location, number, and size of subterminals in Indiana. The specification of the model is the same as that by Ladd and Lifferth with monthly flows of grain to multidestinations and employment of two stages of transhipment. Unlike the approach developed by Ladd and Lifferth, this algorithm can incorporate both quantity demanded at the final destinations and quantities supplied in producing regions. The objective function used in this modelling technique, however, is linear unlike that used by Ladd and Lifferth which does not require linearity in the objective function.

Fuller, Randolf, and Klingman (1976) examined a cotton ginning industry in the Rio Grande Valley of Texas and New Mexico by using a network algorithm. They determined a least cost organizational adjustment of the industry in the face of new storage technology and decreased raw product output. However, the network model cannot determine the optimal number, location, and size of subterminals.

Koo, Thompson and Larson (1985) applied a linear programming model to the U.S. grain transportation system. The model included transport and storage capacity constraints in addition to demand and supply ones. The purpose of the study was to evaluate the impacts of carrier transportation capacity constraints and changes in prices of transportation services on grain marketing and transportation systems.

A network flow algorithm was developed by Barnett, Binkley, and McCarl (1984) for the U.S. grain transportation system to evaluate U.S. port capacity in exporting grains. Consequently, the model treated quantities of grain handled at each U.S. port as endogenous variables. This multiproduct network flow model can only optimize flow of commodities from producing regions to consuming regions. Unlike the model used by Koo et al, this network model cannot be used where production and transport activities are included in order to optimize product location and flows of commodity.

Some studies have been done on transportation of various commodities in Kenya. In 1973, Kenya's Ministry of Co-operative Development looked into transportation costs of different transport systems. Cost comparisons were done to facilitate decision making on whether to use own means or to hire a vehicle. It was clear that the transportation costs incurred using the cooperatively owned vehicles is a function of the kilometres driven per year. Heinrich (1975) looked into the aspect of modes of transport to establish the important mode in hauling fruit and vegetables from important horticultural areas of Central, Eastern, Rift Valley and Nyanza provinces to Nairobi and Mombasa markets. Costs for the different modes of transport were compared in order to establish an economical method of hauling fruits and vegetables. The study used the traditional simple cost approach to arrive at the choice of the mode of transport. Road transport was found to be the most important mode in hauling the produce to these markets.

Some studies have also been done on the tea transport system. Mann (1953) did a study on tea cultivation in the then

Tanganyika Territory. The aim was to investigate the suitability of certain areas of that territory for the production of tea. In order to achieve this, several points were considered to determine the suitability of any area proposed for extensive tea development. The suitability was determined by assessing how close the conditions in an area approached the ideal requirements. As regards cost of transport, the study indicated that the cost of carrying tea to the port was of very vital importance in any attempt to develop the tea industry in East Africa and it became of greater importance as the quality of the tea produced got less. He cautioned that it was necessary to consider very carefully the minimum cost of taking tea to the seaboard before embarking on a large scale tea enterprise in any part of the then Tanganyika.

Etherington (1972) did an econometric study on the smallholder tea production in Kenya. It was observed among other things that predictions of possible output of tea was essential for the optimal phasing of factory construction, provision of transport and the calculation of international debt repayment schedules in Kenya.

A lot of emphasis has been laid on the condition of tea roads in Kenya. The KTDA views good roads as representing not only the simplest means of collecting tea, but also the possibility of bringing significant socio-economic benefits to the tea areas. It was observed that if the transport of green leaf for the Authority's programme was to be continued by road, one of the major considerations was to be improvement of the tea road network (Inbucon, 1968).

Gyllstrom (1977) conducted a study that dealt with the structure and behaviour of Kenya's tea industry. The study was based on the assumption that institutional factors constitute vital space-modelling mechanisms in underdeveloped countries. This assumption was formed into a conceptual model for the character and behaviour of economic activities. The survey results suggested that differences in formal organization have important effects on the spatial orientation of material, capital and service linkages. As regards transportation of tea, he indicated that as the tea districts are high rainfall areas and most of the tea roads are unpaved, transportation problems are at times insurmountable and time schedules are disrupted. The transport problem is aggravated during the flush periods. It was observed that additional costs were being incurred in tea collection operations and in scheduling and maintaining the transport of green leaf to the factories during wet weather.

There is evidence that roads in tea areas have gone from bad to worse. However, it is hoped that with the expected Tea Roads Rehabilitation programme, the government policy that stresses the District as the focus for development (KTDA Annual Report, 1983/84), and the government directive that 80 percent of the tea cess be used to maintain tea roads (MOPW, 1992), greatest efforts will be put into the improvement of tea roads.

Mulinge (1993) did a study on the effects of public sector reform on the tea industry in Kenya. Although he noted that past studies have not been able to quantify the effects of poor roads on the volume of green leaf delivered to factory and the quality of made tea, observers agree that benefits are expected since improvement in tea roads would lead to lower leaf collection costs and would make it possible for KTDA to operate a vehicle fleet designed to minimize transportation costs rather than maximize road access.

The rapid rise in production during the flush period has resulted in congestion in some factories. At such times, leaf has to be transferred from factory to factory, leading to processing delays and fall in green leaf quality especially when the leaf is wet, and contributing to extra mileage over a given year. Some KTDA factories operate at over 150 percent of rated capacity (Mulinge, 1993). The bigger the crop, the more is diverted to areas where there is excess capacity.

Capacity problem in Kenya's tea industry has been explored by Owuor and Orchard (1991) in three smallholder tea factories to assess black tea quality parameters as affected by alternative methods of withering. All tested methods of withering, that is, fresh (unwithered), chemical wither alone, normal (one-stage) wither and two-stage wither produced commercially acceptable teas. The early start in manufacturing that is possible in one-stage and two-stage processes creates additional processing time and allows factory personnel to accept more leaf in the factory. It also reduces the time the leaf is left with a farmer. Thus this improves the leaf handling and the general quality of made teas.

KTDA leaf inspection and collection costs average Ksh.0.51 per kg of green leaf or Ksh. 2.34 per kg of made tea as compared to Ksh. 0.35 in the estates (Mulinge, 1993). This is attributed to differences in amount of leaf handled (vehicle capacity utilization), distance, state of roads, and overheads.

The preceding review indicates that numerous transportation studies have been conducted utilizing transportation and transhipment models. Most of these have dealt with optimum plant locations. Their purpose has been either to determine number, size and location of plants that minimize combined transportation and processing costs, combined assembly, processing and distribution costs, or combined transportation, handling and plant investment costs. In this study, a model is developed that minimizes transportation costs only using the existing plant locations. Past studies conducted on tea have not examined the possibilities of reducing transportation costs by establishing an optimum way of distributing leaf from buying centres to factories.

Other studies dealing with the transport system have been multi-period analyses with multiproduct flows to one final destination or to multidestinations. This study adopts a single-period analysis dealing with one product whereby the choice of the destination for the product is part of the analysis.

Transportation studies in Kenya have mainly been based on the traditional simple cost approach. Such studies have sought to determine the best modes of transport for different commodities. Cost comparisons have been done in order to arrive at a conclusion as to which mode of transport is most suitable. This study differs from such studies in that it employs a transportation model to minimize the smallholder tea transportation costs in Kiambu district given the existing mode of transport.

Transportation issues are usually location specific. However, findings from the Kiambu district study can be extended to similar tea growing environments.

The next chapter discusses the theoretical framework and data analysis.

CHAPTER 4.

4. THEORETICAL FRAMEWORK AND THE MODEL

4.1 Conceptual Framework

A wide range of approaches and solution procedures have been developed to analyze transportation issues. The choice of approaches depends upon the transportation issues to be analyzed and the objectives of the study. Generally, two approaches are used to tackle problems related to transportation:

a) the simple cost approach; and

b) operation/systems research approach.

In the first approach, problems are solved by the traditional cost theory where standard costs for the different means of transport are worked out and compared with the charged rates. The emphasis is based on performance of the transport sector by comparing the cost of different means of transport.

The second method uses the more mathematically oriented systems approach. This involves building an operational model of the whole transport sector and the estimation of optimal strategies for the use of the different means of transport. The approach uses the deterministic optimization models to study potential for improvement in the efficiency of a transport or distribution system. These models are generally categorized into interregional and intraregional models. The intraregional model is designed to evaluate efficiency in physical distribution, competition, marketing structure, and capacity of a transportation system within a region. Interregional models evaluate carrier capacity, handling and storage capacity, distribution, pricing, and competition at the national and international levels (Koo and Larson, 1985).

These two approaches and other research approaches employed in transportation are not unique to transportation. Transportation firms have cost patterns, resource combination criteria, and usually profit motives that are like those of other firms in other parts of a market economy.

Models with space orientation draw on location theory for conceptual support and analytical technique. Other conceptual applications include micro-economic supply, demand, cost, price, industrial organization, and competition theories. They also include mathematical simulation of total logistics systems (transportation, handling, and storage) that minimize resource costs in moving products over space and through time in an orderly marketing system.

Most models dealing with transport issues basically employ equilibrium minimum-cost techniques whether structured as network, linear programming, or quadratic programming models. These techniques are used to address questions related to product flows, infrastructural and mode selection problems.

Competitive structure conditions, ranging from atomistic competition to near monopoly, occur in transportation. Analyses of competitive behaviour of operating firms in transportation are based on industrial organization theory. Responses to a competitive environment are likely no different for transportation firms than elsewhere in the economy (Koo and Larson, 1985).

The linear programming transportation model is designed to simulate the traffic flows in a system taking the transportation system and shipping requirements as inputs. The output of the model is the system network link utilization with its associated costs and performance measures. The most important input to the transport model is the supply of and the demand for the product of each industry in each region. Transport demand is a derived demand. It is generated by the need to move commodities from one location to another. Determining the derived demand for transport is, in fact, one of the important functions of the transport model.

The primary direct impact of the transport system characteristics on the rest of the economy is conveyed in terms of the unit costs, including imputed costs of delay, spoilage, inconvenience, as well as actual charges incurred in shipping various kinds of goods between various origins and destinations. The principal direct effects of a change in the structure of transport costs are:

1. changes in the level of demand at any location for goods whose delivered prices change;
2. changes in the relative quantities of goods supplied from different sources; and
3. changes in profitability of certain production activities in different localities.

These primary reactions to changes in the transport cost pattern have further repercussions that lead to effects on the criterion variables in which we are ultimately interested.

It is assumed that all economic activities take place within cities or villages rather than being continuously distributed over space. Transport is confined to routes between these cities. Special aspects of the transportation process are represented by means of a network composed of links and nodes. The links correspond to transport routes, and nodes represent cities or producing regions. Each commodity is produced at one or more supply nodes and demands for these commodities exist at other nodes within the network.

Commodities are shipped from supply to demand nodes over the links of the network. This representation of the transport network is used as the basis for a description of the problem and the computational scheme.

Links are classified within the model by modal type. This includes transfer points which are represented as links belonging to the transfer model. All modes commonly found in a transport network can be represented. The most common modes include road, rail, waterway, pipeline and air with the appropriate transfer links connecting one mode to another. All modes are represented on a single network, facilitating the computational problem, particularly in the determination of modal choice and routing.

The transporter's choice of mode is typically not a simple choice of water, rail, road or air transport but is a highly subjective selection over a mix of modes, routes and schedules. The choice of mode and route is very much a function of the conditions which exist at any given time on the network and it involves an evaluation of the alternatives available in terms of their ability to satisfy the shipper's needs. It is assumed that the transporters of each commodity consider a number of important factors or costs (direct and indirect) which are meaningful to them. For different commodities, different factors will take on greater or less importance. Once links are rated on basis of performance characteristics in terms of travel factors such as time and cost, paths can be sought which maximize the shipper's utility rating.

An important consideration in the transportation model is the determination of the delivery point for the output from each producing region. It is assumed in the location theory that collection costs are minimized by minimizing distance. A lowest cost (minimum path) subroutine is used to identify the best route based on cost data and distances between nodes. Linear programming is usually used to determine that pattern of shipments from sources to destinations which result in the lowest total transport costs. The problem is formulated as one of minimizing the costs of transportation subject to some constraints.

The purpose of the commodity distribution procedure is to move commodities between points of origin and destination keeping in mind that the buyer's inclination is to purchase them as cheaply as possible. For homogenous products, the linear programming transportation model appears to approximate the behavioral assumptions like additivity and homogeneity, consistently. This is the model used in this study and is discussed further in the next section.

4.2 Linear Programming Formulation of the Transportation Model[1]

The transportation model is concerned with distributing any commodity from any group of supply centres called sources (S), to any group of receiving centres, called destinations (D), in such a way as to minimize total distribution costs. Thus, source Si (i=1,2,..., m) has a supply of s_i units to distribute to destinations, and destination Dj (j=1,2,..., n) has a demand for d_j units to be received from the sources. A basic assumption is that the cost of distributing units from source i to destination j is directly proportional to the number distributed, where c_{ij} denotes the cost per unit distributed.

To make the problem explicit, the following tableau is employed.

	Destinations (D)					
	1	2	.	.	n	Supply
Sources(S) 1	c_{11}	c_{12}	.	.	c_{1n}	s_1
2	c_{21}	c_{22}	.	.	c_{2n}	s_2
.	.	.	.	.	.	.
.	.	.	.	.	.	.
m	c_{m1}	c_{m2}	.	.	c_{mn}	s_m
Demand	d_1	d_2	.	.	d_n	

[1] Section drawn from Anderson et al, 1983.

Each row in this tableau corresponds to an origin and each column corresponds to a destination. The entries in the final column are the supply availabilities at the origins, and the entries in the bottom row are the demand requirements at the destinations. The entries in the cells denote the cost of shipping one unit of a commodity from source i to destination j. Letting Z be total distribution cost, X_{ij} ($i = 1,2,\ldots, m$; $j = 1,2,\ldots, n$) be the number of units to be distributed from source i to destination j, and C_{ij} the corresponding per unit cost, the general formulation of the m-origin, n-destination transportation problem is:

$$\text{Minimize} \quad Z = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} X_{ij}$$

subject to:

$$\sum_{j=1}^{n} X_{ij} = s_i \qquad \text{for } i=1,2,\ldots,m \quad \text{(supply)}$$

$$\sum_{i=1}^{m} X_{ij} = d_j \qquad \text{for } j=1,2,\ldots,n \quad \text{(demand)}$$

$$X_{ij} \geq 0 \qquad \text{for all } i \text{ and } j.$$

This formulation is a special case of linear programming (LP) involving a special type of allocation problem where both the requirements and resources are expressed in terms of one type of unit. It is used to minimize total cost of transportation when:

(i) the number of items, X_{ij}, to be dispatched from, and the number to be received at each point is known; and

(ii) the cost of transportation, C_{ij}, between each pair of points is known.

In transportation research, this LP model simply determines flows of commodities from supply regions, on the basis of an objective function which minimizes total transportation costs. Since the model has demand and supply constraints in each consuming and producing region, it satisfies the spatial equilibrium condition in the study area. The limitation of the model in solving spatial equilibrium problems is the assumption of fixed demand and supply. The model cannot recognize the price response of supply and demand in each region. Hence, the solution obtained from the model cannot be viewed as a global optimal solution, but a conditional optimal solution under predetermined demand and supply conditions.

This LP model has advantage over a quadratic programming (QP) model in transportation research in that the net effects of changes in transportation activities are easier to determine since quantities demanded and supplied are fixed in an LP model. However, a QP model is preferable to an LP model for many areas of marketing research because demand and supply conditions are endogenous rather than fixed.

The above formulation is typical of a balanced transportation problem where total supply is equal to total demand. If total supply exceeds total demand, a dummy destination is introduced, representing the unused production capacity. Where there is excess demand capacity, a dummy source is introduced. Using this LP formulation, the optimal way of transporting a commodity from source i to destination j can be found.

In some transportation problems, shipment from a certain source to a certain destination may be prohibited or impossible. To handle such unacceptable routes, the Big M method is used. This method assigns an extremely high cost, denoted M, to unacceptable shipments in order to keep them out of solution. Thus, if there is a route from an origin to a destination that for some reason cannot be used, this route is assigned a large positive unit transportation cost, M. This route will be avoided because of its high transportation cost, and thus will not enter the solution.

Sensitivity analysis is also done to determine how changes in the co-efficients of a linear program affect the optimal solution. The analysis is done after an optimal solution to the original LP problem has been obtained. The analysis is important since some of the co-efficients change over time. As a result, it is necessary to determine how these changes affect the optimal solution to the original LP problem. Sensitivity analysis can also help determine how much an additional unit of resource is worth and how many units of that resource can be added before diminishing returns set in.

4.3 The Kiambu Tea Transportation Model

A simplified LP model is used to investigate the transportation problems of KTDA operations in Kiambu district. KTDA has four factories in this district. Buying centres are also found within the areas where the factories are located. A detailed formulation of the transportation model in Kiambu district is presented in section 4.4. In this section the general structure of the model, the relevant assumptions and the issue of duality are discussed.

4.3.1 Structure of the Model Used

The transportation model was used to determine the optimum way in which the buying centres could be attached to the four factories in the area of study given some constraints. The basic concept is to minimize total transportation costs, subject to constraints on supply of leaf from buying centres, and processing capacities of factories. Following the usual assumption of location theory that collection costs are minimised by minimising distance, it is logical to expect that leaf from each buying centre is delivered to the nearest factory. The allocation of buying centres to factories was determined based on the weight of leaf collected from each buying centre in the 1992/93 tea production season. The maximum weight collected from each buying centre was not the same for all centres, and there was great variation in day-to-day deliveries of green leaf. A transportation model of the following form was used to analyse the data obtained regarding KTDA's operation in the four leaf bases considered in this study:

$$\text{Minimize} \quad Z = \sum_{i=1}^{n} \sum_{j=1}^{m} X_{ij} C_{ij}$$

subject to:

supply constraints: $\sum_{j=1}^{m} X_{ij} = X_i$

demand constraints: $\sum_{i=1}^{n} X_{ij} \leq X_j$

X_{ij} , X_i , $X_j \geq 0$; $C_{ij} > 0$

where,

Z = total transportation cost

X_{ij} = quantity of green tea leaf transported from leaf collection centre i to factory j.

C_{ij} = Unit cost of transporting tea from collection centre i to factory j

X_i = quantity of green leaf available at collection centre i per production period.

X_j = factory j's processing capacity

n = total number of collection centres

m = total number of factories.

This is an unbalanced transport problem in which demand of leaf at the factories exceeds the available green leaf at the buying centres.

The transportation problem deals with how to transport all the available leaf at the buying centres at minimum cost while not exceeding the capacity of any factory to process leaf. The costs for supplying one kilogramme of green leaf from each buying centre to each factory, C_{ij}, are known. The crop production level of each buying centre over the required period, as well as the processing capacities of the factories are also known.

The LP transportation model selects an optimal pattern of *buying centre attachment to factories out of a large number of possible attachments.* The optimal pattern is the attachment pattern that minimizes transportation costs.

4.3.2 Assumptions of the Model

Each factory is assumed to have the objective of minimizing transport costs and thus will make delivery decisions which will involve the least unit cost. The buying centre and the factory are connected by transport costs. Furthermore, it is assumed that any of the factories can receive green leaf from any of the buying centres and that the leaf is a homogenous commodity. However, there is no cross-hauling of the leaf; factories cannot supply leaf and buying centres can only supply leaf to factories.

Another obvious assumption, although required explicitly in a mathematical sense, is that there can be no negative deliveries. It is also assumed that the level of output at the buying centre and the demand at the factory are known.

Vehicles of the same type are taken as having the same capacity and running speed and it is recognized that tractors may be cheaper to operate on short hauls. Tea roads in all the tea growing areas in the district are assumed to be of the same type and their condition does not affect the transport costs.

4.3.3 Note on Duality

Every linear programming problem has associated with it another linear programming problem, called the dual. In this case, the minimization problem of the transportation model has a related maximization problem. The optimal solution to the dual programming problem provides the following information with respect to the original programming problem:

(i) it yields market prices or rents of the scarce resources allocated in the original problem; and

(ii) it yields the optimal solution to the original problem.

The primal problem is concerned with the allocation of scarce resources; the dual is concerned with pricing, in particular with the marginal shadow prices of resources. Whereas the primal problem focuses on the optimal solution obtainable within the given constraints, the dual shows what might be gained by relaxing these constraints marginally.

With the aid of the duality theorem of LP, a unique set of prices may be derived which correspond to the equilibrium set of commodity flows. Thus given a minimum cost transportation solution, the dual problem is concerned with deriving the vector of prices consistent with this solution.

In developing the dual problem, let yi and yj be the dual variables associated with the primal supply and primal demand constraints respectively. The problem may be set forth in the following equations as:

$$\text{Maximize} \quad \pi = \sum_{i=1}^{n} yiXi + \sum_{j=n+1}^{m} yiXj$$

subject to:

$$\sum_{i=1}^{n} yi \leq C_{ij}$$

$$\sum_{j=n+1}^{m} y\acute{i} \leq C_{ij}$$

where π = returns

n = number of primal supply constraints

m = number of both primal supply and demand constraints

and other variables are as defined in the previous section.

The dual problem, therefore, is a pricing problem. From its solution, it is possible to determine the prices at which the KTDA factories should value their resources so that they can determine the minimum total value at which they would be willing to purchase or sell the resource as is appropriate.

4.4 A Detailed Model and Data

4.4.1 The Model

Kenya Tea Development Authority has four factories in Kiambu district located at Kagwe, Kambaa, Mataara and Theta. Buying centres are also found within the areas where the factories are located. The supply of leaf from each of these centres is given in appendices 1,2,3 and 4. Factory capacity at each location is limited and each has an annual capacity of 15 million kilogrammes of leaf.

Let

XYijF = amount of leaf transported from buying centre XYij to factory F; and

CXYijF = unit cost of transporting leaf from buying centre XYij to factory F

where

XY = KW, KA, MT, TH

ij = 01, 02, ..., 68

F = A, B, C, and D.

Factories A, B, C, and D refer to Kagwe, Kambaa, Mataara and Theta, respectively. KW, KA, MT and TH are the codes for buying centres that deliver tea to Kagwe, Kambaa, Mataara and Theta factories, respectively.

Then the objective is to:

$$\text{Minimize} \quad Z = \sum_{i=1}^{94} \sum_{j=1}^{4} XYijF \; CXYijF$$

subject to:

$$\text{supply constraints:} \quad \sum_{j=1}^{4} XYijF = X_i$$

$$\text{demand constraints:} \quad \sum_{i=1}^{94} XYijF \leq X_j$$

$$XYijF,\ X_i,\ X_j \geq 0 \ ; \ CXYijF > 0$$

The total cost is the sum of the products of the unit transport cost and the amount of leaf transported for each possible delivery route from buying centre to factory.

There are two sets of constraints for this problem. The first set imposed by production capacities guarantees that all the leaf produced in a given area is transported. Thus, for Nyanduma buying centre (KW01), the constraint is:

KW01A = 1,313,610

This implies that all the leaf from Nyanduma is delivered to Kagwe factory.

Similarly, for Gichogocho buying centre (KW33),

KW33A + KW33D = 84,652.

This states that the sum of the kilogrammes of leaf transported from Gichogocho to Kagwe and Theta factories must be 84,652 kilogrammes, this being, the supply level at Gichogocho buying centre. There are 94 constraints of this form arising from these arrangements as shown in appendix 5.

The second set of constraints guarantees that the factories do not exceed their capacities. Thus, for Kagwe factory:

KW01A + KW02A + KW05A + KW06A + KW07A + KW10A + KW26A + KW30A + KW33A + KW37A + KW38A + KW40A + KW42A + KW43A + KW44A + KW45A + KW48A + KW49A + KW50A + KW52A + KW55A + KA15A + KA18A + KA21A + KA23A + KA26A + KA28A + KA37A + KA46A <= 14,687,650

This expression indicates that the amount of leaf delivered to Kagwe factory from the buying centres listed must not exceed the factory's capacity of 14,687,653 kilogrammes of green leaf. Appendix 5 gives such constraints for the other three factories. Finally all the decision variables must be greater than or equal to zero.

The solution of this LP problem gives the optimum, that is, the least-cost transportation schedule for Kenya Tea Development

Authority factories within the study area.

The complete formulation of the problem is given in appendix 6.

A dual linear programming problem developed from the above primal problem is stated as:

$$\text{Maximize } \pi = \sum_{1}^{94} yiX_i + \sum_{95}^{98} yiX_j$$

subject to:

$$\sum_{1}^{94} yi \le C_{ij}$$

$$\sum_{95}^{98} yi \le C_{ij}$$

$$yi,\ yj\ ,\ X_i\ ,\ X_j \ge 0\ ;\ C_{ij} > 0$$

The optimal values of the dual give the dual or marginal prices of the resources used in the primal problem.

4.4.2 Data

Several visits were made to each of the four leaf bases during the survey period. The study was largely based on secondary data compiled from various sources. The sources include factory records, leaf officers' monthly reports available at the leaf bases, monthly reports from KTDA's head office and KTDA annual reports. Supplementary data was obtained through personal interviews and discussions with leaf officers, office clerks, drivers, leaf collection clerks and staff of the Leaf Collection department at the head office.

A list of data requirements was compiled and used as a guideline to the personnel at the leaf bases and factories regarding the type of information to be collected.

Green Leaf Production and Collection

The green leaf data obtained at each leaf base from leaf officer's monthly reports covered the annual total and monthly totals of green leaf collected at each of its buying centres. Other data collected included leaf collection routes and buying centres on the route, and number of days that a buying centre operated per month. Data was obtained for the 1992/93 year as a benchmark year.

Distances from buying centre to mother (current) factory and to a possible alternative factory for delivery of leaf, were obtained from schematics and scale maps of individual networks prepared by Sir Alexander Gibb and Partners Limited (MOPW, 1992).

Leaf Collection Vehicle Fleet

Data on composition of collection vehicle fleet was obtained from KTDA head office. This included information on vehicle type, operating costs of spares, fuel, oil, tyres, insurance and road licence on monthly basis. Additional information included green leaf collected and total kilometres travelled by each vehicle, total annual kilogrammes per kilometre carried and total cost per kilometre.

4.4.3 Method of Analysis

The tea transportation problem was analysed using a computer software package called LINDO (Linear, INteractive, Discrete, Optimizer). Data preparation for LINDO involved collection of information on decision variables, objective function co-efficients, supply and demand constraints.

Two different sets of figures were used in the analysis. The first set involved use of vehicle running costs comprising of fuel, spares, oil, tyres, insurance and road licence expenses. In the second part of the analysis, total leaf collection costs were used. These costs include staff salaries, office expenses, telephone and electricity bills, medical and uniform expenses, and money spent on the purchase of sisal bags, in addition to vehicle running costs.

Decision Variables

Buying centre-factory combinations indicating the possibility of delivering leaf from a given buying centre to a given factory are the decision variables. In transportation problems, it may not be possible to establish a route from every origin to every destination, that is, some routes may be unacceptable. The Big M method handles this case by assigning an arbitrarily high unit transportation cost, M, to any unacceptable route. The minimum transportation cost solution will avoid the unacceptable route because of its high unit cost.

In this study, it was necessary to reduce the number of variables and the model to a manageable size. Thus an alternative way of handling such prohibited routes was adopted. The corresponding decision variables, X_{ij}s were removed from the LP formulation of the problem.

To avoid computational constraints, some aggregation of buying centres was done. Buying centres delivering leaf to the same factory and having equal or almost equal unit transportation costs were aggregated together under one buying centre's code. The supply of leaf from such a buying centre is the sum of supply from each of the buying centres that it represents. This aggregation procedure did not apply for the buying centres whose possibility of transfer from mother factory to a different factory were being investigated. Each of these buying centres together with the possible delivery points was represented as a decision variable in the formulation. The following tables indicate the numbers (No.), means and standard deviations (sd.) of important data variables before and after aggregation.

Table 4.1 Numbers, Means and Standard Deviations of Variables by Factory before Aggregation.

Factory	Growers No.	sd.	Buying Centres No.	sd.	Green leaf weight	sd.
Kagwe	3,331	453	57	2	12,347,365	270,293
Kambaa	3,624	160	46	9	11,487,233	1,130,425
Mataara	4,348	564	58	3	14,288,664	1,671,007
Theta	3,836	52	59	4	12,347,369	270,290
Total	15,139		220		50,470,631	
Mean	3,784		55		12,617,658	

Table 4.2 Numbers, Means and Standard Deviations of Variables by Factory after Aggregation.

Factory	Growers No.	Growers sd.	Buying Centres No.	Buying Centres sd.	Green leaf weight	Green leaf sd.
Kagwe	3,331	453	21	2	12,347,365	270,293
Kambaa	3,624	160	25	2	11,487,233	1,130,425
Mataara	4,348	564	20	3	14,288,664	1,671,007
Theta	3,836	52	29	6	12,347,369	270,290
Total	*15,139*		*95*		50,470,631	
Mean	3,784		23		12,617,658	

The buying centre coded KW03 (Kagwe) had its supply of leaf subtracted from the processing capacity of Kagwe factory (its mother factory) giving a figure of 14,687,650 kilogrammes instead of 15,000,000 kilogrammes of leaf. This is because this buying centre is located next to the factory and therefore no transportation cost as defined in the study, is incurred in this case. Following this, KW03A did not appear as a decision variable, either on its own or in aggregation.

Estimation of Objective Function Co-efficients

The unit transportation costs incurred in delivering green leaf from a buying centre to a factory form the objective function co-efficients. In estimating the unit transport costs, the distance from each buying centre to its mother factory was calculated. Since the ideal distance between a buying centre and a factory was taken to be 16.09 km (Inbucon, 1968), all those centres that are more than 16.09 km from their mother factories were considered to be inappropriately located. In such cases, distances to alternative factories were calculated. However, there were cases in Kambaa and Mataara networks where alternative delivery points were not found. For Kambaa leaf base, no other possible delivery point was found for Bibilioni buying centre (KA24) because it is at the south-western extreme end of the network, where the network borders only estate factories. Mataara leaf base has only three buying centres that are more than 16.09 km from it. These centres are even further away from Theta factory which would have been considered as a possible alternative point of delivery. Therefore, in these cases leaf from the buying centres has to be delivered to the mother factories.

Using the average cost per kilometre for each leaf base and the weight of green leaf collected at each buying centre, unit transport costs were estimated. These costs were calculated for each possible shipping route and are given in Appendix 7.

Supply and Demand Constraints

The supply constraints represent the available green leaf at each of the buying centres, either for an individual buying centre or for a buying centre representing other buying centres aggregated under its code. The annual green leaf collected at each buying centre was used in the model, as there are large fluctuations in buying centre intake from day-to-day and also due to seasonal climatic changes. The use of annual data provides a "smoothing" effect.

The demand constraints in this case refer to the processing capacities of the factories. With the exception of Kagwe factory, the factories have an annual capacity of 15 million kilogrammes of leaf, which must not be exceeded.

In the next chapter, the results of the study are presented.

CHAPTER 5.

5. RESULTS AND DISCUSSIONS

The results of the LP model are presented and discussed in the following sections. These results are compared with the existing situation and causes of divergences are discussed.

The output from the computer program (*LINDO*) *is shown in* Appendix 8. The solution comprises of the objective function value, values of the decision variables, reduced costs, slack or surplus information, and dual prices. Sensitivity analysis gives ranging information on the objective function co-efficients and the right-hand side values.

Discussions in this chapter are based on the results obtained from the analysis where vehicle running costs were used. Brief discussions are made on reduced costs of both optimal and non-optimal decision variables, dual prices of supply and processing capacities, and sensitivity analysis of the optimal solution.

5.1 Existing and Optimal Solutions

The results of the analysis are shown in Table 5.1. These results show that regardless of the type of costs used, lower costs prevail in the optimal plans as compared to the current ones.

Table 5.1: Transport Costs (Ksh) for Existing and Optimal Situations

Costs used in Analysis	Existing Situation *	Optimal Situation	Percent Change
Vehicle Running Costs	14,225,208.00	10,857,720.00	23.67
Leaf Collection Costs	25,871,487.90	18,566,080.00	28.24

* : Leaf Officers' Monthly Reports.

The LINDO output shows that the minimum cost solution occurs with an objective function value of 10,857,720. This means that the minimum total vehicle running cost is Ksh. 10,857,720. The current plan gives a cost of Ksh.14,225,208, indicating that the optimal solution reduces running costs by 23.67 percent. The same improvement applies to the average transport cost.

In the case where total leaf collection costs are used, the minimum cost solution is given as 18,566,080. This differs from the current level of costs by Ksh.7,305,407.90, a 28.24 percent reduction in total leaf collection costs. Therefore, with respect to the postulated hypotheses, the second hypothesis that the transportation costs incurred in the optimal and existing patterns of buying centre attachment to factories are the same, cannot be accepted.

Analysis using total vehicle running costs and total leaf collection costs, gives the same optimum deliveries of green leaf except for six buying centres namely, Kiawangware (MT22), Munandaini (MT52), Iruguini (TH26), Mathage (TH35), Muchugu

(TH36) and Mitunduini (TH40). These differences arise owing to different buying centres being aggregated together under each of the above centres. However, this does not affect deliveries from individual buying centres to factory once the aggregate figure for green leaf is split into leaf intake at each individual centre.

The reduced costs of nonbasic variables, dual prices and the objective co-efficient ranges differ in the two cases since they depend on the objective co-efficients used. Except for the six buying centres mentioned above, the righthand side ranges are the same. The capacity utilization is also the same in both cases with the levels of unused capacities being as shown in Table 5.8.

5.2 Optimality of Green Leaf Transportation

The values of the decision variables in the computer output (Appendix 8) show the optimal amounts to be transported over each route. The minimum total vehicle running cost is incurred when the transportation system is arranged in such a way that leaf deliveries are made only for those buying centre-factory combinations (decision variables) with non-zero solution values. Those combinations with zero values indicate that no leaf should be delivered from the given buying centres to the given factories if transportation costs are to be minimized. The optimum deliveries are presented in Table 5.2.

The cells in Table 5.2 that have numbers indicate the variables (buying centre-factory combinations) which appear in the final basic solution.

Table 5.2: <u>Final Optimum Deliveries of Green Leaf in Kiambu District (kgs)</u>

Origins	Destinations: Kagwe	Kambaa	Mataara	Theta
Nyanduma	1,313,610			
Gachoire	2,015,156			
Kamahindu	1,497,209			
Ngenya	1,513,333			
Kariguini	1,532,025			
Gathugu	646,154.5			
Wamwika	446,812.5			
Murera	268,791			
Gichogocho	-			84,652
Gathiriga	-			289,176
Njihia	-			278,993.5
Gathiru	-			320,952
Gatina	-			190,423
Mariguitu	-			206,432.5
Gatama	-			175,178.5
Murangoini	382,305.5			
Muriranja	147,957.5			
Njaguini	166,265			
Muiri	46,500			
Mathonda	-			127,474.5
Karinga	386,520.5			
Matimbei		2,153,671		
Kagaa		971,466.5		
Kambaa		481,644		
Gitiha		1,408,229		
Mathanja		650,779		
Kamahia		131,537.5		
Ngeteti		1,883,629		
Matuguta		1,171,789		
Gataka		492,618		
Bathi	245,945.5	-		
Nyamuthanga	194,847.5	-		
Karangi	112,540	-		
Kinungu		208,873.5		
Githogoiyo	65,787	-		
Bibilioni		112,151		
Githirioni		54,196		
Makimei	103,368.5	-		
Gikira	61,576.5	-		
Kihenjo		325,390.5		
Ngambaka		142,141.5		
Ngochi		52,748		
Wairura	103,179	-		
Gakindu		67,061.5		
Nyanjogu		143,878		
Karigi	148,186.5	-		

Origins	Destinations			
	Kagwe	Kambaa	Mataara	Theta
Kamunyaka			657,534.5	
Gakoe			914,948	
Mataara			1,057,186	
Ndiko			3,164,103	
Mariaini			1,361,991	
Kanyoni			1,167,504	
Kaibere			586,553	
Muchakai			1,844,956	
Kagonye			749,819	
Kiawangware			1,062,585	
Karega			88,625	
Kiangunu			301,102	
Kirera			189,539	
Kagunya			56,174.5	
Munandaini			628,708	
Ngaraka			97,619	
Kamithunu			76,266	
Tambaya			58,110.5	
Mitundu			98,028.5	
Gatina			126,314	
Mundoro				1,057,018
Gacharage				682,736
Ituramiro				429,798
Karangi				1,453,167
Gitwe				1,327,721
Roi				842,914
Kibiro				492,427.5
Iruguini				564,746.5
Wanugu				968,166
Kirangi				455,703.5
Mathage				967,519
Muchugu				407,125
Mitunduini				496,218
Kimee				132,319.5
Gitugu				225,616.5
Mairanga				160,402
Kandakomu				234,440
Karanu				220,406.5
Gakunye				265,599.5
Ngaragacha				83,826.5
Numi				89,579
Waruiru				84,307
Gwathuo				100,187
Mukui				67,064
Kingoe				41,718
Karinga				86,489.5
Manjengo				52,990.5
Kahuruko				36,655

Source: Calculated from the Model

These numbers represent the quantities of leaf involved in the optimum delivery system. For example, the optimum solution indicates that Nyanduma buying centre should supply Kagwe factory with 1,313,610 kilogrammes of leaf; Kahuruko buying centre should supply Theta factory with 36,655 kilogrammes of leaf. The cells with dashes represent buying centre-factory combinations that have zero values in the optimal solution and are considered as non-optimal delivery routes.

This attachment of buying centres to factories (Table 5.2) has been selected by LINDO out of 97 (n+m-1) possible patterns of attachment. It is the delivery pattern that minimizes transportation costs of green leaf from the various buying centres to the four tea factories serving the tea growing area in Kiambu district. Other buying centre-factory combinations are possible. These would ensure that tea leaf from each of the buying centres is delivered to one of the four factories. However, the resulting delivery system would not minimize costs of transportation. Therefore, the transport costs used in obtaining the optimum set of flows are less than for every other possible alternative delivery which is not made.

Several observations can be made when comparing both primal and dual solutions. First, the optimal solution to the dual problem, as expected, is exactly the same as the optimal solution to the original (primal) problem. The objective function value in both cases is 10,857,720. This means that the minimum total transportation cost incurred is Ksh. 10,857,720. Secondly, ninety-four out of the ninety-eight dual variables (Y1-Y94) have positive values and the corresponding primal constraints are exactly satisfied. This indicates that if a resource is valued at a positive marginal price in the optimal primal solution, all the resources should be used. In this study, this means that all the green leaf supplied by the buying centres should be transported to the factories. The other four dual variables (Y95, Y96, Y97 and Y98) are factory capacities and have zero optimal values meaning that the corresponding primal constraints are overly satisfied. Since the capacities are not fully utilized in the optimal primal solution, the marginal value of the capacities is zero.

The optimal values of the dual problem give the marginal prices of the resources. These values indicate whether units of resources should be sold or purchased. If these minimum prices (values of dual problem) exist in the market, then the factories should be indifferent between the alternatives of manufacturing made tea and selling the green leaf to other manufacturers. If the market prices are higher than the dual minimum prices, then the factories should prefer to sell the green leaf delivered to them and if the market prices are lower, then the factories should prefer to buy more green leaf from other sources and manufacture it. Thus, the dual minimum prices give a measure for evaluating the marginal value of additional capacity of the resources. Increasing capacity may require a change in the optimal production schedule. The dual optimal values are discussed further in section 5.4.

5.3 Reduced Costs of Variables

The reduced costs associated with both basic and non-basic variables are described in this section. Reduced cost indicates by how much the unit transportation cost of each decision variable would have to improve before it would be possible for that variable to assume a positive value in the optimal solution. The reduced costs associated with variables not in the optimal solution are penalties to the optimal transportation cost which would occur when one unit of these activities is forced into the optimal plan, all things remaining the same. These costs are zero for those activities which already appear in the optimal solution.

Some buying centre-factory combinations have optimal values equal to zero. These combinations incur higher transportation costs in comparison to others. They do not allow transportation of leaf to take place between centres and factories. It is worth finding out by how much the unit transportation costs should be reduced for it to be worth transporting leaf between the sources and destinations indicated by these combinations. The reduced costs associated with these variables, are in fact, the necessary decreases in unit transportation costs. Therefore, if leaf were to be transported from any of the centres with a non-zero reduced cost, then the unit transportation cost would have to be reduced by an amount equivalent to the reduced cost. For example, Table 5.3 shows that Gichogocho-Kagwe combination has a reduced cost of 0.87. It can be inferred that the transport cost between Gichogocho buying centre and Kagwe factory would have to decrease by at least Ksh.0.87 per kilogramme before any leaf would be transported between the two, given the alternative delivery possibilities and costs.

Table 5.3: Reduced Costs of Variables (Ksh/kg

Buying centre-factory combination	Reduced Cost
Gichogocho-Kagwe	0.87
Gathiriga-Kagwe	0.22
Njihia-Kagwe	0.28
Gathiru-Kagwe	0.24
Gatina-Kagwe	0.40
Mariguitu-Kagwe	0.31
Gatama-Kagwe	0.46
Mathonda-Kagwe	0.56
Bathi-Kambaa	0.44
Nyamuthanga-Kambaa	0.59
Karangi-Kambaa	1.04
Githogoiyo-Kambaa	1.35
Makimei-Kambaa	0.83
Wairura-Kambaa	1.07
Karigi-Kambaa	0.88

Source: Calculated from the Model

The reduced costs can also be interpreted as the amount by which the total transportation cost will be degraded or increased for each kilogramme of leaf that is transported from any buying centre-factory combination that is associated with a particular non-zero reduced cost. For example, Gichogocho buying centre could deliver a kilogramme of leaf to Kagwe factory only at a Ksh.0.87 loss, or by increasing total transport costs by Ksh.0.87 for every kilogramme of leaf that is transported. It is therefore possible to cost a non-optimal decision by using the reduced costs.

5.4 Dual Prices

The dual prices of the resources indicate by how much the total transportation costs would be increased or decreased whenever a unit of a constraining resource is added or withdrawn from the system, all other things remaining constant. In a *minimization LP the dual price is the negative of the* corresponding shadow price. The shadow price is the change in the total transportation cost per unit change in the resources (amount of green leaf supplied by the buying centres). Shadow or dual price represents effects of small changes in green leaf available at the buying centres - it is the change in transportation cost as a result of a one unit change in the resource level. Thus, the dual price can be interpreted as the value of an extra unit of a resource. When a constraining resource is not used up entirely in the optimal solution, it takes a zero dual price. However, when it is used up, it becomes a limiting constraint and then takes a non-zero dual price.

The supply constraints were such that all available supply was exhausted. Therefore, they have non-zero dual prices. For example, the figures in Table 5.4 indicate that if the supply capacity of Githirioni buying centre was to be increased by a small amount δ, the resultant increase in total cost after re-arranging the optimal transportation plan would be Ksh ($1.64 \times \delta$), everything else remaining the same. The figure 1.64 is, therefore, the dual price for Githirioni. Similarly, the decrease in total cost by reducing the amount of leaf available at Githirioni by a small amount δ would be Ksh ($1.64 \times \delta$).

Table 5.4: Dual Prices for Buying Centres (Ksh/kg)

Buying Centre	Dual Price	Buying Centre/Factory	Dual Price
Nyanduma	-0.20	Mariaini	-0.05
Gachoire	-0.09	Kanyoni	-0.28
Kamahindu	-0.04	Kaibere	-0.45
Ngenya	-0.12	Muchakai	-0.15
Kariguini	-0.14	Kagonye	-0.22
Gathugu	-0.28	Kiawangware	-0.32
Wamwika	-0.24	Karega	-0.85
Murera	-0.56	Kiangunu	-0.91
Gichogocho	-0.20	Kirera	-0.49
Gathiriga	-0.07	Kagunya	-1.43
Njihia	-0.04	Munandaini	-0.35
Gathiru	-0.03	Ngaraka	-0.76
Gatina	-0.09	Kamithunu	-1.04
Mariguitu	-0.13	Tambaya	-1.96
Gatama	-0.08	Mitundu	-0.42
Murangoini	-0.33	Gatina	-0.66
Muriranja	-0.47	Mundoro	-0.01
Njaguini	-0.41	Gacharage	-0.16
Muiri	-0.65	Ituramiro	-0.12
Mathonda	-0.09	Karangi	-0.06
Karinga	-0.34	Gitwe	-0.22
Matimbei	-0.19	Roi	-0.09
Kagaa	-0.24	Kibiro	-0.18
Kambaa	-0.01	Iruguini	-0.38
Gitiha	-0.07	Wanugu	-0.23
Mathanja	-0.14	Kirangi	-0.25
Kamahia	-0.47	Mathage	-0.36
Ngeteti	-0.04	Muchugu	-0.28
Matuguta	-0.11	Mitunduini	-0.30
Gataka	-0.33	Kimee	-0.67
Bathi	-0.07	Gitugu	-0.32
Nyamuthanga	-0.18	Mairanga	-0.50
Karangi	-0.20	Kandakomu	-0.30
Kinungu	-0.64	Karanu	-0.60
Githogoiyo	-0.50	Gakunye	-0.55
Bibilioni	-1.34	Ngaragacha	-0.79
Githirioni	-1.64	Numi	-0.46
Makimei	-0.23	Waruiru	-0.85
Gikira	-1.65	Gwathuo	-0.73
Kihenjo	-0.51	Mukui	-1.07
Ngambaka	-0.39	Kingoe	-1.93
Ngochi	-1.02	Karinga	-0.89
Wairura	-0.25	Manjengo	-1.46
Gakindu	-1.09	Kahuruko	-2.42
Nyanjogu	-0.71	Kagwe	0
Karigi	-0.22	Kambaa	0
Kamunyaka	-0.24	Mataara	0
Gakoe	-0.08	Theta	0
Mataara	-0.02		
Ndiko	-0.18		

Source: Calculated from the Model

There are limits within which δ can lie. These limits are known as right-hand side ranges. In fact, the dual price of -1.64 indicates that if the green leaf at Githirioni buying centre is increased by 10,000 kilogrammes from 54,196 to 64,196 kilograms, the value of the objective function will not improve, but will get worse by the amount of Ksh 16,400 (1.64x 10,000), other things remaining constant. *It increases from Ksh. 10,857,720 to* Ksh. 10,874,120. On the other hand, reducing Githirioni's supply by 10,000 kilogrammes improves the objective function value by Ksh.16,400, registering a decrease from Ksh.10,857,720 to Ksh.10,841,320.

The factory processing capacities were not fully utilised as indicated by the slack or unused capacities associated with the respective rows in the optimal solution. These capacities have been given a zero valuation. The value is zero which means that the "opportunity cost" of an additional unit of processing capacity at any of the factories is zero. This is consistent with the fact that these factories have idle capacity following the optimum schedule of transportation, and costs would not be reduced by making more processing capacity in these factories available. Since all the capacities have not been used, not much value is likely to be placed on them and extra units are, therefore, worthless.

5.5 Sensitivity Analysis

The optimal plan described above showed the overall effects of resource constraints acting simultaneously. Sensitivity analysis determines the range over which the unit transportation costs and green leaf supply levels at the buying centres may vary without affecting the list of variables in the optimal solution or the shadow prices. Right-hand side ranging defines the conditions for the stability of the optimal plan when leaf supply at an individual buying centre is increased or reduced, under "ceteris paribus" conditions. Objective ranging indicates the outcome of changing the unit transportation cost of an individual buying centre- factory combination in the objective function. These two ranges indicate the lower and upper limits within which the supply levels and the unit transport costs can vary without changing the optimal minimum transportation cost of Ksh. 10,857,720.

5.5.1 Objective Co-efficient Ranges

It is useful to know the effects of changes in the unit transportation cost on the optimal solution or the minimum total transportation cost. Since the unit transportation costs of the buying centre-factory combination are used in the computation of the optimal solution, any change in their values will result in a change in the value of optimal solution. But small changes in these unit costs may not change the set of variables in the optimal solution. Larger changes however, will cause a change in the list of variables in the solution and will move the optimal solution from its current value. As long as the actual value of the unit cost is within the computed range, the optimal solution will remain unchanged. This is called the range of optimality for the unit transportation costs. Table 5.5 shows the objective ranging information for the optimal situation. All the other buying centre-factory combinations do not have finite limits for unit transportation costs and are not included in this table. Others lack either the lower or the upper limit.

Table 5.5: <u>Objective Ranging for Variables</u>

Buying centre-factory combination	Lower Limit	Upper Limit
Gichogocho-Kagwe	0.20	+inf
Gichogocho-Theta	-inf	1.07
Gathiriga-Kagwe	0.07	+inf
Gathiriga-Theta	-inf	0.29
Njihia-Kagwe	0.04	+inf
Njihia-Theta	-inf	0.32
Gathiru-Kagwe	0.03	+inf
Gathiru-Theta	-inf	0.27
Gatina-Kagwe	0.09	+inf
Gatina-Theta	-inf	0.49
Mariguitu-Kagwe	0.13	+inf
Mariguitu-Theta	-inf	0.44
Gatama-Kagwe	0.08	+inf
Gatama-Theta	-inf	0.54
Mathonda-Kagwe	0.09	+inf
Mathonda-Theta	-inf	0.65
Bathi-Kagwe	-inf	0.51
Bathi-Kambaa	0.07	+inf
Nyamuthanga-Kagwe	-inf	0.77
Nyamuthanga-Kambaa	0.18	+inf
Karangi-Kagwe	-inf	1.24
Karangi-Kambaa	0.20	+inf
Githogoiyo-Kagwe	-inf	1.85
Githogoiyo-Kambaa	0.50	+inf
Makimei-Kagwe	-inf	1.06
Makimei-Kambaa	0.23	+inf
Gikira-Kagwe	-inf	5.34
Gikira-Kambaa	1.65	+inf
Karigi-Kagwe	-inf	1.10
Karigi-Kambaa	0.22	+inf

Source: Calculated from the Model.

The range of optimality for Gichogocho-Kagwe (KW33A) is: $0.2 \leq KW33A \leq \infty$. As long as the per unit cost of transporting leaf from Gichogocho to Kagwe factory is greater than or equal to Ksh.0.20, the given transportation cost will be optimal. There is no upper bound on how much the unit cost may be increased.

The same analysis holds for all variables which are not in the optimal solution. Specifically it can be shown that there is no upper limit on how much the unit cost can be increased. Since the variables are not in the optimal solution, increases in the unit transportation costs, however much they are, cannot alter the optimal transport cost. In addition, the lower limit on how much the unit transport cost for Githogoiyo-Kagwe can be reduced before it is profitable to transport leaf from Githogoiyo to Kagwe is calculated by subtracting the allowable decrease of 0.87 from the current unit cost. This allowable decrease is equal to the reduced cost associated with Githogoiyo-Kagwe combination. The cost cannot be lowered by more than the reduced cost without making it profitable to transport leaf from Githogoiyo to Kagwe. This would obviously cause a change in the optimal solution.

For the variables in the solution, two different patterns of ranges of optimality emerge. Some of them have no lower limits while others have neither lower nor upper bounds. For example, the range of optimality for Karangi-Kagwe (KA21A) is $-\infty \leq KA21A \leq 1.24$. Therefore, as long as the unit transport cost from Karangi buying centre to Kagwe factory is less than or equal to Ksh. 1.24, the given transport cost will remain optimal. Ksh.1.24 is the unit transportation cost incurred while delivering leaf from Karangi buying centre to Kambaa factory.

Karangi currently delivers its leaf to Kambaa factory. However, it is cheaper to transport leaf from Karangi to Kagwe factory. The unit transportation cost is Ksh.0.20 as opposed to Ksh.1.24 per kilogramme of leaf, when leaf is delivered from Karangi to Kambaa factory. The optimal solution indicates that leaf from Karangi should be delivered to Kagwe factory. If the unit transport cost from Karangi to Kagwe becomes higher than Ksh.1.24, then it would be worthwhile to stop delivering leaf to Kagwe and start delivering to Kambaa, which will then have a lower unit transportation cost. This change of delivery points will obviously cause a change in the minimum transportation cost. Therefore the upper limit for Karangi becomes 1.24. There is no lower limit on how much the co-efficient can be reduced. Since Karangi-Kagwe combination is already in the optimal solution, a decrease in unit transportation cost would not cause a change in the set of variables in the optimal solution. This holds true for all buying centres with the possibility of transporting leaf to more than one delivery point.

For Nyanduma-Kagwe combination (KW01A), one of the variables with infinite values, the objective range is $-\infty \le \text{KW01A} \le \infty$. Its unit transport cost is subject to wide variability. This is because leaf from Nyanduma cannot be delivered to any other factory except Kagwe. Deliveries to other factories are regarded as unacceptable or prohibited routes, in which case the corresponding decision variables are dropped out of the formulation. Such buying centres have no option but to deliver leaf to the factories indicated in the buying centre-factory combinations. Therefore no possible increases or decreases in unit transportation costs would cause such variables to be excluded from the optimal solution.

5.5.2 Right-hand Side Ranges

Dual prices have been seen to be useful in predicting the effect of small changes in the green leaf supplied by a buying centre on the transportation cost. The value of the dual price may be applicable only for small changes in the resource level. As one resource continues to increase, other constraints will become binding and reduce the rate of change in the transportation cost. Therefore, the interpretation related to dual prices is only valid within a certain range whereby the change in the resource level is not large enough to change the solution mix or the list of variables in the solution. This range is known as the right-hand side range or range of feasibility. As long as the resource level stays within this range, the associated dual price gives the change in the value of the transportation cost per unit change in the resource level.

Table 5.6 gives upper limits for the resources at the buying centres and factories. The results indicate that most resources in the model have finite upper limits in the optimal plan. Only four of the resources do not have upper limits, which means that no increases in the resource levels, however much they are, would alter the optimal policy. All the resources apart from these four, have zero as the lower limit.

Table 5.6: Right-hand Side Ranging for Resource Level

Buying Centre	Upper Limit	Buying Centre/ Factory	Upper Limit
Nyanduma	4604090.0	Mariaini	2073325.0
Gachoire	5305636.0	Kanyoni	1878838.0
Kamahindu	4787689.0	Kaibere	1297887.0
Ngenya	4803813.0	Muchakai	2556290.0
Kariguini	4822505.0	Kagonye	1461153.0
Gathugu	3936634.5	*Kiawangware*	1773919.0
Wamwika	3737292.5	Karega	799959.0
Murera	3558371.0	Kiangunu	1013436.0
Gichogocho	1064001.0	Kirera	900873.0
Gathiriga	1268525.0	Kagunya	767508.5
Njihia	1258342.5	Munandaini	1340042.0
Gathiru	1300301.0	Ngaraka	808953.0
Gatina	1169772.0	Kamithunu	787600.0
Mariguitu	1185781.5	Tambaya	769444.5
Gatama	1154527.5	Mitundu	809362.5
Murangoini	3672785.5	Gatina	837648.0
Muriranja	3438437.5	Mundoro	2036367.0
Njaguini	4356745.0	Gacharage	1662085.0
Muiri	3336980.0	Ituramiro	1409147.0
Mathonda	1106823.5	Karangi	2432516.0
Karinga	3677000.5	Gitwe	2307070.0
Matimbei	6701868.0	Roi	1822263.0
Kagaa	5519663.0	Kibiro	1471776.5
Kambaa	5029841.0	Iruguini	1544095.5
Gitiha	5956426.0	Wanugu	1947515.0
Mathanja	5198976.0	Kirangi	1435052.5
Kamahia	4679734.5	Makohokoho	1299857.5
Ngeteti	6431826.0	Mathage	1946868.0
Matuguta	5719986.0	Muchugu	1386474.5
Gataka	5040815.0	Mitunduini	1475567.0
Bathi	3536425.5	Kimee	1111668.5
Nyamuthanga	3485327.5	Gitugu	1204965.5
Karangi	3403620.0	Mairanga	1139751.0
Kinungu	4757070.0	Kandakomu	1213789.0
Githogoiyo	3356267.0	Karanu	1199755.5
Bibilioni	4660348.0	Gakunye	1244948.5
Githirioni	4602393.0	Ngaragacha	1063175.5
Makimei	3393848.5	Numi	1068928.0
Gikira	3352056.5	Waruiru	1063656.0
Kihenjo	4873587.5	Gwathuo	1079536.0
Ngambaka	4690338.5	Mukui	1046413.0
Ngochi	4600945.0	Kingoe	1021067.0
Wairura	3393659.0	Karinga	1065838.5
Gakindu	4615258.0	Manjengo	1032339.5
Nyanjogu	4692075.0	Kahuruko	1016004.0
Karigi	3438666.5	Kagwe	+inf
Kamunyaka	1368868.5	Kambaa	+inf
Gakoe	1626282.0	Mataara	+inf
Mataara	1768520.0	Theta	+inf
Ndiko	3875437.0		

For the buying centres, the lower limit is obtained by subtracting the given allowable decrease from the original resource level, while an addition of allowable increase gives the upper limit. The allowable increases are equivalent to the excess processing capacity associated with the factory to which the *given buying centre takes its leaf. The original resource* levels give the allowable decreases. For instance, row 83 (Appendix 5) has an allowable decrease of 160,402. This is equivalent to the resource level or the amount of leaf supplied by Mairanga buying centre (TH45) which appears as row 84 in the LP formulation. The allowable increase is 979,348.5 which is equal to excess capacity at Theta factory where Mairanga buying centre takes its leaf. For this example the ranges are:

lower limit 0

upper limit 1,139,750.5

Thus, the supply of leaf from Mairanga buying centre to Theta factory can be increased up to 1,139,750.5 kilogrammes or decreased down to 0 kilogramme per year with the predicted effect on transportation cost. The zero lower limit means that it is possible for Mairanga not to supply any leaf to Theta factory. Similar interpretation applies for all the other buying centres.

The case for the factory processing capacities is different. Not all the capacity is being used. There is slack or unused capacity of 3,290,480, 4,548,197, 711,334, and 979,349 associated with Kagwe, Kambaa, Mataara and Theta factories, respectively. For Kagwe factory, the righthand ranges are:

lower limit 11,397,170

upper limit ∞

The lower range in this case is obtained by subtracting the slack capacity which is given as the allowable decrease, from the factory's existing capacity. The rationale for the lower limit is that not all the processing capacity is used in the present optimal solution, so that some of the capacity can be eliminated and still have slack. Since the most slack that can be eliminated is all of it, the reduction of the original capacity by any larger amount would change the variable mix. Since all the processing capacity is not being used, increasing it without limit can have no effect on the optimal solution. In fact, raising it can only raise the slack by the amount of the change in the processing capacity. No other change is possible, and the variable mix must remain exactly the same. Therefore the upper range is infinity (∞). Within these ranges, there will be no change in the minimum transportation cost since the dual price on these constraints is zero.

5.6 Rearrangement of Buying Centres

Optimum buying centre attachments to factories that are given in Table 5.2 show substantial divergence from the existing situation. Sixteen buying centre-factory combinations that are not in the existing transportation plan appear in the optimal plan as possible delivery routes. This implies that the first hypothesis which postulated that the optimal and existing patterns of attaching buying centres to factories do not differ, is rejected. Rearrangement in the attachment of buying centres to factories has occurred. Table 5.7 shows the changes that have taken place.

Table 5.7: Rearrangement of Buying Centres Attachment to Factory

	Factory Attached To	
Buying Centre	Existing Situation*	Optimal Situation
Gichogocho	Kagwe	Theta
Gathiriga	Kagwe	Theta
Njihia	Kagwe	Theta
Gathiru	Kagwe	Theta
Gatina	Kagwe	Theta
Mariguitu	Kagwe	Theta
Gatama	Kagwe	Theta
Mathonda	Kagwe	Theta
Bathi	Kambaa	Kagwe
Nyamuthanga	Kambaa	Kagwe
Karangi	Kambaa	Kagwe
Githogoiyo	Kambaa	Kagwe
Makimei	Kambaa	Kagwe
Gikira	Kambaa	Kagwe
Wairura	Kambaa	Kagwe
Karigi	Kambaa	Kagwe

*: Leaf Officers' Reports.

Relocation of buying centres in terms of their delivery points only affected three factories, namely Kagwe, Kambaa and Theta. Mataara factory which was the first to be established was not affected by the rearrangement in the optimal plan. The results showed that 8 out of the 57 buying centres attached to Kagwe factory needed to be relocated to Theta factory. These buying centres represent 13.55 percent of the leaf delivered to Kagwe. In return, Kagwe would receive leaf from 8 buying centres that had been formerly attached to Kambaa factory. This amount of leaf represents 8.70 percent of leaf deliveries made at Kambaa. When compared with the existing situation, the optimal plan showed that the leaf deliveries made at the factories would decrease by 5.46 and 8.70 percent for Kagwe and Kambaa factories, respectively. However, deliveries made at Theta factory recorded a 13.55 percent increase while no changes occurred in deliveries made at Mataara factory. These changes in leaf deliveries affect the utilization of the factories' processing capacity.

Table 5.8 shows the changes in the slack or unused capacities of factories as a result of rearrangement in the delivery points for buying centres. There is reduced capacity utilization for Kagwe and Kambaa factories. However, while Mataara maintains the same capacity utilization, Theta has an increase in the volume of leaf intake.

Table 5.8: Unused Capacities of Factories (Kg)

Factory	Existing Situation	Optimal Situation	Percent Change
Kagwe	2,652,635.0	3,290,480.0	(24.05)
Kambaa	3,512,766.5	4,548,197.0	(29.48)
Mataara	711,335.5	711,334.0	negligible[c]
Theta	2,652,631.5	979,349.0	63.08

[c]: Differences are negligible due to rounding off of supply figures.

All the buying centres involved in the rearrangement except Gathiru, are uneconomical according to KTDA's standards. This is because their annual green leaf intake is below 300,000 kilogrammes, a level the KTDA considers economical at any buying centre. Two centres, Githogoiyo and Gikira have an annual intake that is below 75,000 kgs which means that they are not able to pay for the services of a leaf collection clerk. Therefore, apart from contributing to high transport costs because of the long distances involved in collecting leaf from them, these centres also add to the costs due to their low volume intake.

The new allocation of buying centres among the factories may affect waiting time at the buying centres. The collection lorries generally leave the leaf base after 11.00 a.m. to travel to the farthest centre on their route, arriving there at about mid-day. Long delays are usually recorded at the first buying centre because farmers may not deliver leaf early enough for the truck to load quickly. In order to start deliveries to the factory, the available leaf may be loaded and delivered, and a second trip made later in the day. However, a reduction in distances to be travelled may reduce waiting time at the farthest buying centre and other centres as well, since the collection lorries do not have to leave the factory as early as they presently do. It may also eliminate the need of making a second trip to the farthest centre in the same day.

Sometimes, lorries may return to the factory with partial loads when farmers fail to deliver leaf in good time. Shorter haulage distances may help to avoid partial loads and the need for a driver to switch to another route in order to make up a full load which is not always convenient. It may also contribute towards making sure that the KTDA fleet provides for maximum capacity. This may mean that drivers will not have to work for excessive hours and delays that involve moving some leaf until the following morning are avoided.

The farmers' response to this new arrangement may lead to an increase in green leaf production as farmers potentially increase plucking in response to the shorter distance which may have to be travelled to the alternative delivery point; the less time spent transporting green leaf being time available for plucking. Farmers who hire labour for plucking may find themselves able to attract additional labour as a result of additional time available for plucking. This is likely to alleviate one of the transport-related problems faced by KTDA, namely, loss of green leaf production, since it will reduce plucking losses that result from shorter plucking time per day and non-plucking.

Relocation of buying centres to factories also affects proceeds from the sale of made tea. There is a net decrease in made tea sales of Ksh. 198,258.00. This is, however, a small decrease compared to the cost savings amounting to Ksh. 3,367,488.00 that arise from the new arrangement. Even with a decrease in income from the sale of made tea, there is a net improvement on transport costs of Ksh.3,169,230.00.

The next chapter summarizes the findings of the study. Recommendations and conclusion are also presented. The chapter concludes with the limitations of the study and the need for further research.

CHAPTER 6.

6. SUMMARY, RECOMMENDATIONS AND CONCLUSION

6.1 Summary

Leaf collection in the smallholder tea sub-sector of Kenya, influences not only the income levels of the tea growers, but has important consequences for foreign exchange earnings and subsequent generation of public fund. This study was conducted to determine the transportation costs incurred in the current KTDA transport system and to establish the least cost distribution of buying centres among the existing factories in Kiambu district. A linear programming model was used to establish an optimal pattern of attaching buying centres to factories, that is commensurate with the minimization of transport costs in the district.

The results indicate that the optimal pattern of attaching buying centres to factories differs from the existing one, both in levels of transportation costs incurred and the attachment of buying centres to factories. The optimal delivery routes result in lower transport costs than the current ones. There are cost savings of 23.67 percent on green leaf transport costs when the optimal pattern of buying centre attachment to factories is employed. A rearrangement in the attachment of buying centres to factories affected three of the four factories in the district. Sixteen buying centre-factory combinations that are not in the existing transportation plan appear in the optimal plan as possible delivery routes. Some of these buying centres are uneconomical according to KTDA's standards. The establishment of new buying centres irrespective of the volume of green leaf throughput coupled with long haulage distances has led to even higher costs of transportation. Useful planning information on reduced costs of activities, dual prices of resources, and righthand side and objective ranging for resource levels and unit transport costs, was also obtained.

6.2 Recommendations

Overall, the results of the study show that the optimal pattern of attaching buying centres to factories is associated with lower transportation costs when compared with the existing pattern of arrangement. The results suggest that to improve the tea transportation system in Kiambu district and hence minimize the costs incurred, at least the following policy measures shall be noticed.

The lower transportation costs of the optimal plan result from a change in delivery routes involving sixteen buying centres and three factories. This means that a re-organization of the buying centre attachment to factories is necessary in order to improve on the transportation of green leaf from buying centres to factories.

This re-organization may shed light on the location of tea factories in future. Mataara factory which was the first to be commissioned in the district was not affected by the re-organization. This may possibly mean that this factory was optimally located unlike the other three factories. Therefore, serious location considerations need to be made in the event of establishing other tea factories in the district.

The level of transport costs incurred is greatly dependent on the location of the leaf base/tea factory within the tea growing area. Thus, where the buying centres are very far from the mother base/factory, relatively higher costs are incurred owing to the long distances over which green leaf has to be hauled in order to reach the factory. In this regard, the historical development of leaf base operations has left some centres attached to inconvenient factories but it has been shown that a change in the attachment of buying centres to factories enables them to deliver leaf to a closer delivery point. In cases where two or more networks interact, proper planning in the routing of tea collection needs to be done to avoid unnecessarily large networks and associated high transport costs.

During the past few years, the tea transportation costs within the district increased as a result of development of tea in marginal areas. Due to good second payments which have been paid to farmers, there has been a tendency to plant tea beyond tea boundaries without notifying the district tea office. This practice has significantly affected transport requirements and created problems in different ways. First, it has encouraged the establishment of new buying centres irrespective of the green leaf throughput. Some of the buying centres involved in the re-organization are uneconomical in that their annual green leaf intake is below 300,000 kilogrammes. Secondly, it has encouraged the extension of tea production to areas poorly served by the existing road network. Finally, it has also encouraged the production of tea in sub-economic units. The district tea office has taken measures on tea legalization to ensure that the crop is grown within the marked boundaries. However, these measures need to be reinforced if tea transportation costs within the district are to be minimized.

In the past, KTDA zonal boundaries transcended administrative boundaries. Currently and where possible, efforts are being made to group together leaf bases that are in the same administrative district. This policy appears to be more of a political than economic problem in the tea industry. It is likely to lead to unnecessarily large networks. It would also hinder the exploitation of the possible benefits of the re-organization and re-arrangement that would result if such a study were carried out in two or more tea zones. KTDA should entirely bear the responsibility of demarcating zonal boundaries depending on the magnitude and extent of its operations in any tea growing area.

The production of tea in high rainfall areas with steep road gradients raises many transport problems. Furthermore, tea is plucked every 7 to 10 days and so production is continuous. Access during all seasons requires good roads. Tea roads need to be rehabilitated and the Government directive that 80 percent of the tea cess collected be used to maintain tea collection roads, would contribute towards this endeavour (MOPW, 1992). Improvement in tea roads would lead to lower leaf collection costs and would make it possible for KTDA to operate a vehicle fleet designed to minimize transportation costs rather than maximize road access. Currently, KTDA uses Bedford J6, Isuzu lorries and "SAME" tractors, which are more expensive to operate but efficient given the distances covered.

During periods of green leaf flush, seldom it has been necessary to divert leaf from one factory to another where there is excess capacity. These diversions need to be well planned since they contribute to extra mileage and raise transportation costs. Leaf transportation is also complicated by the very limited controls that KTDA is able to impose over the production and plucking of tea. Planning green leaf collection to minimize costs should be effectively undertaken by having control over when and where plucking of leaf should take place during the flush period.

6.3 Conclusion

The purpose of this study was to determine the optimum way of attaching tea buying centres to factories in Kiambu district in order to minimize transportation costs. The current transport system in the district incurs higher transportation costs than it would otherwise do if the optimal transport system were adopted. There are cost savings of 23.67 percent when the optimal pattern of buying centre attachment of factories is employed indicating the need for a re-organization in the attachment of buying centres to factories if transportation costs are to be minimized. These costs can be reduced further by ensuring that tea is not grown in marginal areas and that the criterion used to select buying centres to serve a given factory, considers relative advantage in terms of distance. Non-economic considerations be minimized in the demarcation of zonal boundaries. It is also important to maintain good tea roads in order to enable KTDA to operate vehicles designed to minimize transportation costs rather than maximize access. Farmers should be encouraged to allow for the re-organization, since this would mean higher yields and better prices for their crop.

6.4 Limitations and Need for Further Research

This study suffers from a number of drawbacks. First, only one tea production season was considered. This means that a static model was used. A research that introduces dynamism would complement the results of this study. Secondly, to make the problem computationally feasible, aggregation of buying centres was done. The results may be different if disaggregate figures were used. Furthermore, the study was district specific. The results may not be applicable to other smallholder tea areas in Kenya. However, the findings from the Kiambu district study can indicate the need for a similar study in other tea growing districts.

In the study, tea roads in the district were assumed to be of the same type. Thus, the influence of the road condition on the unit transportation cost was not reflected. A study that incorporates parametric analysis of unit transportation costs based on the condition of the tea roads, would be needed. Such a study would include different levels of unit transportation costs and their impact on the optimal transportation cost. This would provide more information for better decisions.

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APPENDIX 1

LEAF DELIVERIES TO KAGWE FACTORY

Buying Centre	Buying Centre Code	No. of Growers	Cummulative Weight
Nyanduma	KW 01	66	253,206.00
Gachoire	KW 02	116	391,637.00
Kagwe	KW 03	133	312,347.50
Gatamaiyu	KW 04	90	286,524.00
Kamahindu	KW 05	83	302,395.00
Ngenya	KW 06	84	357,833.50
Kariguini	KW 07	123	429,869.00
Kaguongo	KW 08	82	363,098.50
Chiboini	KW 09	73	314,872.00
Gathugu	KW 10	92	204,999.00
Gacheru	KW 11	62	204,513.50
Karatina	KW 12	90	299,941.00
Gathoito	KW 13	93	323,965.50
Mugumoini	KW 14	104	446,113.00
Nduriri	KW 15	40	218,670.50
Kamuchege	KW 16	82	514,295.00
Magomano	KW 18	98	301,183.50
Mwenji	KW 19	119	514,092.50
Gituma	KW 20	67	212,414.00
Githongo	KW 21	41	179,545.50
Mbariki	KW 22	69	318,067.00
Kamungu	KW 23	88	204,507.50
Ndiriini	KW 24	43	176,880.50
Gituamba	KW 25	29	165,571.50
Wamwika	KW 26	24	126,820.00
Kairini	KW 27	37	129,991.50
Kinenie	KW 28	43	162,952.50
Ngamba	KW 29	33	166,921.00
Murera	KW 30	59	55,665.00
Kiangutu	KW 31	66	240,929.00
Karaya	KW 32	54	210,000.50
Gichogocho	KW 33	47	84,652.00
Kiawambe	KW 34	27	100,640.00
Mitundu	KW 35	42	157,768.50
Kiawaihenya	KW 36	38	116,073.00
Gathiriga	KW 37	62	289,176.00
Njihia	KW 38	77	278,993.50
Gachika	KW 39	86	393,541.50
Gathiru	KW 40	47	320,952.00
Wangui	KW 41	39	319,992.50
Gatina	KW 42	55	190,423.00
Mariguiti	KW 43	72	206,432.50
Gatama	KW 44	50	175,178.50
Murangoini	KW 45	36	137,194.00
Mwarano	KW 46	27	65,748.00
Kanake	KW 47	34	96,153.00
Muriranja	KW 48	20	82,209.50
Njaguini	KW 49	29	119,645.50

Buying Centre	Buying Centre Code	No. of Growers	Cummulative Weight
Muiri	KW 50	1	46,500.00
Kamunyuini	KW 51	16	120,785.50
Mathonda	KW 52	47	127,474.50
Wambari	KW 53	27	46,619.50
Njagauchekeini	KW 54	32	103,196.50
Karinga	KW 55	42	98,158.50
Ndongoro	KW 56	24	83,848.50
Gatina	KW 57	23	54,274.50
Gachema	KW 58	48	141,913.00
Leaf Base Totals		3331	12347365.00

APPENDIX 2

LEAF DELIVERIES TO KAMBAA FACTORY

Buying Centre	Buying Centre Code	No. of Growers	Cummulative Weight
Matimbei	KA 01	175	437,279.00
Kagaa	KA 02	110	263,704.50
Kamahia	KA 10	82	131,537.50
Kambaa	KA 03	165	481,644.00
Gitiha	KA 04	113	338,127.50
Githiga	KA 05	128	465,673.00
Mathanja	KA 06	90	373,830.50
Runguri	KA 07	106	766,890.00
Iriaini	KA 08	145	386,826.00
Kamburu	KA 09	165	408,082.00
Ngeteti	KA 11	163	927,228.00
Matuguta	KA 12	194	551,267.00
Gataka	KA 13	63	147,554.50
Waingere	KA 14	59	260,323.00
Bathi	KA 15	99	245,945.50
Muimia	KA 16	66	204,514.00
Gatina	KA 17	84	198,533.00
Nyamuthanga	KA 18	99	194,847.50
Karigi	KA 46	44	148,186.50
Gitwe	KA 19	97	272,819.00
Mahuru	KA 20	58	276,948.50
Karangi	KA 21	22	112,540.00
Kinungu	KA 22	45	125,422.50
Githogoiyo	KA 23	33	65,787.00
Bibilioni	KA 24	62	112,151.00
Githioroini	KA 25	23	54,196.00
Makimei	KA 26	29	103,368.50
Gitindoi	KA 27	52	332,924.00
Gikira	KA 28	17	25,033.50
Gatheki	KA 29	73	219,106.00
Gitamaiyu	KA 30	169	415,721.00
Irioko	KA 31	43	143,188.50
Kaminditi	KA 32	33	132,302.00
Kihenjo	KA 33	51	196,925.00
Ngambaka	KA 34	48	142,141.50
Ngochi	KA 35	40	52,748.00
Raini	KA 36	42	294,613.50
Wairura	KA 37	28	103,179.00
Gatitu	KA 38	158	374,838.00
Gathangari	KA 39	68	189,511.00
Kimaiti	KA 40	44	128,465.00
Gakindu	KA 41	25	67,061.50
Murango	KA 42	49	203,846.50
Ruiru	KA 43	52	83,451.50
Nyamu	KA 44	40	146,531.00
Nyanjogu	KA 45	72	143,878.00
NTZ	KA 98	1	36,543.00
Leaf Base Totals		3624	11487233.00

APPENDIX 3

LEAF DELIVERIES TO MATAARA FACTORY

Buying Centre	Buying Centre Code	No. of Growers	Cummulative Weight
Kamunyaka	MT 01	88	286,795.00
Gakoe	MT 02	122	509,461.00
Mataara	MT 03	108	404,058.00
Gatunguru	MT 04	81	361,930.50
Ndiko	MT 05	125	380,441.00
Kanjabi	MT 06	171	549,475.00
Kamuhindi	MT 07	75	276,186.00
Mariaini	MT 08	95	397,020.50
Gituamba	MT 09	155	354,878.00
Kanyoni	MT 10	191	304,546.00
Igamba	MT 11	141	253,295.00
Kaibere	MT 12	135	261,999.00
Thuraku	MT 13	74	313,586.00
Kamagoto	MT 14	119	404,571.00
Kariri	MT 15	83	405,487.00
Gachege	MT 16	174	512,003.50
Muchakai	MT 17	49	233,897.50
Miugu	MT 18	114	479,852.00
Kagonye	MT 19	103	289,454.00
Gichuka	MT 20	65	259,554.50
Kiriko	MT 21	91	371,990.00
Kiawangware	MT 22	46	195,824.50
Thweri	MT 23	66	300,886.50
Nyakibai	MT 24	67	345,459.50
Mutura	MT 25	86	263,343.00
Ndunduini	MT 26	79	318,934.50
Gathanji	MT 27	117	236,622.00
Kahata	MT 28	77	204,876.00
Kianwe	MT 29	71	229,967.00
Karimu	MT 30	23	139,912.00
Karugutu	MT 31	47	157,279.50
Nyathaini	MT 32	109	282,957.00
Gathugu	MT 33	77	166,128.50
Thunguri	MT 36	73	303,085.50
Karega	MT 37	74	88,625.00
Kimangu	MT 38	40	137,324.50
Muriko	MT 39	65	225,222.50
Gitira	MT 40	77	188,259.00
Karangari	MT 41	46	173,276.00
Chania	MT 42	66	300,576.00
Kiangunu	MT 43	18	87,085.00
Karani	MT 44	83	389,936.50
Kairimu	MT 45	45	187,371.50
Kirera	MT 46	35	189,539.00
Raini	MT 47	31	142,792.50
Kagunya	MT 48	32	56,174.50
Kiawaruchu	MT 49	49	118,275.00
Kahembeta	MT 50	80	158,425.50
Ithanji	MT 51	13	107,396.50

Buying Centre	Buying Centre Code	No. of Growers	Cummulative Weight
Munandaini	MT 52	46	157,320.50
Ngaruiya	MT 53	25	138,958.00
Ngaraka	MT 54	43	97,619.00
Mugambwa	MT 55	32	129,187.00
Kamithunu	MT 56	30	76,266.00
Tambaya	MT 57	27	58,110.50
Mitundu	MT 58	18	98,028.50
Gatina	MT 59	45	126,314.00
Munyawa	MT 60	30	96,742.00
NTZ	MT 98	1	4,083.50
Leaf Base Totals		4348	14,288,664.00

APPENDIX 4

LEAF DELIVERIES TO THETA FACTORY

Buying Centre	Buying Centre Code	No. of Growers	Cummulative Weight
Mundoro	TH 01	101	450,090.00
Gacharage	TH 02	77	247,189.50
Ituramiro	TH 03	121	429,798.00
Karangi	TH 04	87	367,238.50
Ndundu	TH 05	133	351,204.50
Gitwe	TH 06	132	329,037.00
Ruaburu	TH 08	60	256,245.00
Roi	TH 09	172	436,461.00
Matheri	TH 10	50	348,960.50
Githiururi	TH 11	43	257,967.50
Kabuteti	TH 15	76	346,200.00
Gaithete	TH 16	113	326,403.00
Cununiki	TH 18	63	212,268.50
Kibiro	TH 19	72	318,063.00
Mahindu	TH 21	56	212,419.50
Mathika	TH 23	33	167,204.50
Githunguri	TH 24	50	174,364.50
Kihara	TH 25	57	101,617.00
Iruguini	TH 26	46	139,543.50
Magomano	TH 27	66	293,044.00
Wanugu	TH 28	73	273,572.00
Karatu	TH 29	123	338,619.50
Kirangi	TH 30	78	256,516.50
Muthunguchi	TH 31	134	419,652.50
Gathaite	TH 32	140	240,201.50
Makohokoho	TH 33	178	320,508.50
Mutunguru	TH 34	51	185,001.50
Mathage	TH 35	58	211,463.50
Muchugu	TH 36	75	231,843.50
Gatimu	TH 37	34	188,818.50
Miiri	TH 38	115	355,974.50
Mitunduini	TH 40	55	203,853.50
Kimee	TH 41	117	132,319.50
Gathomi	TH 42	46	164,483.00
Gitugu	TH 43	85	225,616.50
Kamutua	TH 44	69	212,904.00
Mairanga	TH 45	38	160,402.00
Kandakomu	TH 46	56	234,440.00
Ndekere	TH 47	52	206,791.50
Kibere	TH 49	25	80,050.00
Karanu	TH 50	15	83,933.00
Gitare	TH 51	30	136,473.50
Gakunye	TH 52	26	105,085.00
Ngaragacha	TH 53	45	83,826.50
Kwandaua	TH 54	60	195,962.50
Muhiriga	TH 55	31	125,415.00
Uchekeini	TH 56	19	49,867.00
Karurume	TH 57	47	79,460.50
Kamahiga	TH 58	52	160,514.50

Buying Centre	Buying Centre Code	No. of Growers	Cummulative Weight
Numi	TH 59	28	89,579.00
Munyuini	TH 60	46	199,187.00
Waruiru	TH 61	29	84,307.00
Gwathuo	TH 62	13	100,187.00
Mukui	TH 63	16	67,064.00
Kingoe	TH 64	11	41,718.00
Karinga	TH 65	73	86,489.50
Kibuya	TH 66	29	142,502.50
Manjengo	TH 67	30	52,990.50
Kahuruko	TH 68	25	36,655.00
NTZ	TH 98	1	17,800.50
Leaf Base Totals		3836	12347368.50

APPENDIX 5 : SUPPLY AND DEMAND CONSTRAINTS

Supply Constraints

```
 2)   KW01A =     972040.5
 3)   KW02A =     2015156
 4)   KW05A =     1497209
 5)   KW06A =     1513333
 6)   KW07A =     1532025
 7)   KW10A =     646154.5
 8)   KW26A =     446812.5
 9)   KW30A =     267891
10)   KW31A =     341569
11)   KW33A + KW33D =     84652
12)   KW37A + KW37D =     289176
13)   KW38A + KW38D =     278993.5
14)   KW40A + KW40D =     320952
15)   KW42A + KW42D =     190423
16)   KW43A + KW43D =     206432.5
17)   KW44A + KW44D =     175178.5
18)   KW45A =     382305.5
19)   KW49A =     166265
20)   KW50A =     46500
21)   KW52A + KW52D =     127474.5
22)   KW55A =     386520.5
23)   KA01B =     2153671
24)   KA02B =     971466.5
25)   KA03B =     481644
26)   KA04B =     1408229
27)   KA06B =     650779
28)   KA10B =     131537.5
29)   KA11B =     1883629
30)   KA12B =     1171789
31)   KA13B =     492618
32)   KA15A + KA15B =     245945.5
33)   KA18A + KA18B =     194847.5
34)   KA21A + KA21B =     112540
35)   KA22B =     208873.5
36)   KA23A + KA23B =     65787
37)   KA24B =     112151
38)   KA25B =     54196
39)   KA26A + KA26B =     103368.5
40)   KA28A + KA28B =     25033.5
41)   KA33B =     325390.5
42)   KA34B =     142141.5
43)   KA35B =     52748
44)   KA37A + KA37B =     103179
45)   KA41B =     67061.5
46)   KA45B =     143878
47)   KA46A + KA46B =     148186.5
48)   MT01C =     657534.5
49)   MT02C =     914948
50)   MT03C =     991306.5
51)   MT05C =     3164103
52)   MT08C =     1361991
53)   MT10C =     1167504
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54) MT12C = 586553
55) MT17C = 1844956
56) MT19C = 749819
57) MT22C = 1058501
58) MT37C = 88625
59) MT43C = 302102
60) MT46C = 189539
61) MT48C = 56174.5
62) MT52C = 628708
63) MT54C = 97619
64) MT56C = 76266
65) MT57C = 58110.5
66) MT58C = 98028.5
67) MT59C = 126314
68) TH01D = 1057018
69) TH02D = 682736
70) TH03D = 429798
71) TH04D = 1444267
72) TH06D = 1318820
73) TH09D = 842914
74) TH19D = 492427.5
75) TH26D = 564746.5
76) TH28D = 968166
77) TH30D = 455703.5
78) TH33C + TH33D = 320508.5
79) TH35D = 967519
80) TH36D = 407125.5
81) TH40D = 496218
82) TH41D = 132319.5
83) TH43D = 225616.5
84) TH45D = 160402
85) TH46C + TH46D = 234440
86) TH50D = 220406.5
87) TH52D = 265599.5
88) TH53D = 83826.5
89) TH59D = 89579
90) TH61D = 84307
91) TH62D = 100187
92) TH63D = 67064
93) TH64D = 41718
94) TH65D = 86489.5
95) TH67D = 52990.5
96) TH68D = 36655

Demand Constraints

97) KW01A + KW02A + KW05A + KW06A + KW07A + KW10A + KW26A + KW30A + KW31A + KW33A + KW37A + KW38A + KW40A + KW42A + KW43A + KW44A + KW45A + KW48A + KW49A + KW50A + KW52A + KW55A + KA15A + KA18A + KA21A + KA23A + KA26A + KA28A + KA37A + KA46A <= 14,687,650

98) KA01B + KA02B + KA03B + KA04B + KA06B + KA10B +
KA11B + KA12B + KA13B + KA15B + KA18B + KA21B +
KA22B + KA23B + KA24B + KA25B + KA26B + KA28B +
KA33B + KA34B + KA35B + KA37B + KA41B + KA45B +
KA46B <= 15,000,000

99) MT01C + MT02C + MT03C + MT05C + MT08C + MT10C +
MT12C + MT17C + MT19C + MT22C + MT37C + MT43C +
MT46C + MT48C + MT52C + MT54C + MT56C + MT57C +
MT58C + MT59C + TH33C + TH46C <= 15,000,000

100) KW33D + KW37D + KW38D + KW40D + KW42D + KW43D +
KW44D + KW52D + *TH01D* + *TH02D* + *TH03D* + *TH04D* +
TH06D + *TH09D* + *TH19D* + *TH26D* + *TH28D* + *TH30D* +
TH33D + TH35D + TH36D + TH40D + TH41D + TH43D +
TH45D + TH46D + TH50D + TH52D + TH53D + TH59D +
TH61D + TH62D + TH63D + TH64D + TH65D + TH67D +
TH68D <= 15,000,000

APPENDIX 6: DATA PREPARED FOR LINDO

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MIN     0.20 KW01A + 0.09 KW02A + 0.04 KW05A + 0.12 KW06A +
        0.14 KW07A + 0.28 KW10A + 0.24 KW26A + 0.56 KW30A +
        1.07 KW33A + 0.20 KW33D + 0.29 KW37A + 0.07 KW37D +
        0.32 KW38A + 0.04 KW38D + 0.27 KW40A + 0.03 KW40D +
        0.49 KW42A + 0.09 KW42D + 0.44 KW43A + 0.13 KW43D +
        0.54 KW44A + 0.08 KW44D + 0.33 KW45A + 0.47 KW48A +
        0.41 KW49A + 0.65 KW50A + 0.65 KW52A + 0.09 KW52D +
        0.34 KW55A + 0.19 KA01B + 0.24 KA02B + 0.01 KA03B +
        0.07 KA04B + 0.14 KA06B + 0.47 KA10B + 0.04 KA11B +
        0.11 KA12B + 0.33 KA13B + 0.07 KA15A + 0.51 KA15B +
        0.18 KA18A + 0.77 KA18B + 0.20 KA21A + 1.24 KA21B +
        0.64 KA22B + 0.50 KA23A + 1.85 KA23B + 1.34 KA24B +
        1.64 KA25B + 0.23 KA26A + 1.06 KA26B + 1.65 KA28A +
        5.34 KA28B + 0.51 KA33B + 0.39 KA34B + 1.02 KA35B +
        0.25 KA37A + 1.32 KA37B + 1.09 KA41B + 0.71 KA45B +
        0.22 KA46A + 1.10 KA46B + 0.24 MT01C + 0.08 MT02C +
        0.02 MT03C + 0.18 MT05C + 0.05 MT08C + 0.28 MT10C +
        0.45 MT12C + 0.15 MT17C + 0.22 MT19C + 0.32 MT22C +
        0.85 MT37C + 0.91 MT43C + 0.49 MT46C + 1.43 MT48C +
        0.35 MT52C + 0.76 MT54C + 1.04 MT56C + 1.96 MT57C +
        0.42 MT58C + 0.66 MT59C + 0.01 TH01D + 0.16 TH02D +
        0.12 TH03D + 0.06 TH04D + 0.22 TH06D + 0.09 TH09D +
        0.18 TH19D + 0.38 TH26D + 0.23 TH28D + 0.25 TH30D +
        0.36 TH35D + 0.28 TH36D + 0.30 TH40D + 0.67 TH41D +
        0.32 TH43D + 0.50 TH45D + 0.37 TH46C + 0.30 TH46D +
        0.60 TH50D + 0.55 TH52D + 0.79 TH53D + 0.46 TH59D +
        0.85 TH61D + 0.73 TH62D + 1.07 TH63D + 1.93 TH64D +
        0.89 TH65D + 1.46 TH67D + 2.42 TH68D

  SUBJECT TO
        2)    KW01A =     1313610
        3)    KW02A =     2015156
        4)    KW05A =     1497209
        5)    KW06A =     1513333
        6)    KW07A =     1532025
        7)    KW10A =     646154.5
        8)    KW26A =     446812.5
        9)    KW30A =     267891
       10)    KW33A + KW33D =    84652
       11)    KW37A + KW37D =    289176
       12)    KW38A + KW38D =    278993.5
       13)    KW40A + KW40D =    320952
       14)    KW42A + KW42D =    190423
       15)    KW43A + KW43D =    206432.5
       16)    KW44A + KW44D =    175178.5
       17)    KW45A =     382305.5
       18)    KW48A =     147957.5
       19)    KW49A =     166265
       20)    KW50A =     46500
       21)    KW52A + KW52D =    127474.5
       22)    KW55A =     386520.5
       23)    KA01B =     2153671
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24) KA02B = 971466.5
25) KA03B = 481644
26) KA04B = 1408229
27) KA06B = 650779
28) KA10B = 131537.5
29) KA11B = 1883629
30) KA12B = 1171789
31) KA13B = 492618
32) KA15A + KA15B = 245945.5
33) KA18A + KA18B = 194847.5
34) KA21A + KA21B = 112540
35) KA22B = 208873.5
36) KA23A + KA23B = 65787
37) KA24B = 112151
38) KA25B = 54196
39) KA26A + KA26B = 103368.5
40) KA28A + KA28B = 61576.5
41) KA33B = 325390.5
42) KA34B = 142141.5
43) KA35B = 52748
44) KA37A + KA37B = 103179
45) KA41B = 67061.5
46) KA45B = 143878
47) KA46A + KA46B = 148186.5
48) MT01C = 657534.5
49) MT02C = 914948
50) MT03C = 1057186
51) MT05C = 3164103
52) MT08C = 1361991
53) MT10C = 1167504
54) MT12C = 586553
55) MT17C = 1844956
56) MT19C = 749819
57) MT22C = 1062585
58) MT37C = 88625
59) MT43C = 302102
60) MT46C = 189539
61) MT48C = 56174.5
62) MT52C = 628708
63) MT54C = 97619
64) MT56C = 76266
65) MT57C = 58110.5
66) MT58C = 98028.5
67) MT59C = 126314
68) TH01D = 1057018
69) TH02D = 682736
70) TH03D = 429798
71) TH04D = 1453167
72) TH06D = 1327721
73) TH09D = 842914
74) TH19D = 492427.5
75) TH26D = 564746.5
76) TH28D = 1288675
77) TH30D = 455703.5
78) TH35D = 967519
79) TH36D = 407125.5

```
80)   TH40D =    496218
81)   TH41D =    132319.5
82)   TH43D =    225616.5
83)   TH45D =    160402
84)   TH46C + TH46D =    234440
85)   TH50D =    220406.5
86)   TH52D =    265599.5
87)   TH53D =    83826.5
88)   TH59D =    89579
89)   TH61D =    84307
90)   TH62D =    100187
91)   TH63D =    67064
92)   TH64D =    41718
93)   TH65D =    86489.5
94)   TH67D =    52990.5
95)   TH68D =    36655
96)   KW01A + KW02A + KW05A + KW06A + KW07A + KW10A +
      KW26A + KW30A + KW33A + KW37A + KW38A + KW40A +
      KW42A + KW43A + KW44A + KW45A + KW48A + KW49A +
      KW50A + KW52A + KW55A + KA15A + KA18A + KA21A +
      KA23A + KA26A + KA28A + KA37A + KA46A <=   14687650

97)   KA01B + KA02B + KA03B + KA04B + KA06B + KA10B +
      KA11B + KA12B + KA13B + KA15B + KA18B + KA21B +
      KA22B + KA23B + KA24B + KA25B + KA26B + KA28B +
      KA33B + KA34B + KA35B + KA37B + KA41B + KA45B +
      KA46B <=   15000000

98)   MT01C + MT02C + MT03C + MT05C + MT08C + MT10C +
      MT12C + MT17C + MT19C + MT22C + MT37C + MT43C +
      MT46C + MT48C + MT52C + MT54C + MT56C + MT57C +
      MT58C + MT59C + TH46C <=   15000000

99)   KW33D + KW37D + KW38D + KW40D + KW42D + KW43D +
      KW44D + KW52D + TH01D + TH02D + TH03D + TH04D +
      TH06D + TH09D + TH19D + TH26D + TH28D + TH30D +
      TH35D + TH36D + TH40D + TH41D + TH43D + TH45D +
      TH46D + TH50D + TH52D + TH53D + TH59D + TH61D +
      TH62D + TH63D + TH64D + TH65D + TH67D + TH68D
      <=   15000000
END
```

APPENDIX 7: UNIT TRANSPORTATION COSTS (KSH./KG)

Origins (buying centres)	Destinations (factories)			
	Kagwe	Kambaa	Mataara	Theta
KW01	0.20	-[a]	-	-
KW02	0.09	-	-	-
KW03	0.00	-	-	-
KW04	0.08	-	-	-
KW05	0.04	-	-	-
KW06	0.12	-	-	-
KW07	0.17	-	-	-
KW08	0.14	-	-	-
KW09	0.09	-	-	-
KW10	0.28	-	-	-
KW11	0.36	-	-	-
KW12	0.09	-	-	-
KW13	0.08	-	-	-
KW14	0.14	-	-	-
KW15	0.09	-	-	-
KW16	0.04	-	-	-
KW18	0.04	-	-	-
KW19	0.11	-	-	-
KW20	0.04	-	-	-
KW21	0.09	-	-	-
KW22	0.12	-	-	-
KW23	0.18	-	-	-
KW24	0.29	-	-	-
KW25	0.12	-	-	-
KW26	0.24	-	-	-
KW27	0.16	-	-	-
KW28	0.14	-	-	-
KW29	0.05	-	-	-
KW30	0.56	-	-	-
KW31	0.21	-	-	-
KW32	0.27	-	-	-
KW33	1.07	-	-	0.20
KW34	0.21	-	-	-
KW35	0.12	-	-	-
KW36	0.54	-	-	-
KW37	0.29	-	-	0.07
KW38	0.32	-	-	-
KW39	0.19	-	-	-
KW40	0.29	-	-	0.03
KW41	0.25	-	-	-
KW42	0.50	-	-	0.09
KW43	0.44	-	-	0.13
KW44	0.54	-	-	0.08
KW45	0.33	-	-	-
KW46	0.48	-	-	-
KW47	0.58	-	-	-
KW48	0.47	-	-	-
KW49	0.41	-	-	-

Origins (buying centres)	Destinations (factories)			
	Kagwe	Kambaa	Mataara	Theta
KW50	0.66	-	-	-
KW51	0.20	-	-	-
KW52	0.65	-	-	0.09
KW53	0.41	-	-	-
KW54	0.32	-	-	-
KW55	0.35	-	-	-
KW56	0.35	-	-	-
KW57	0.28	-	-	-
KW58	0.32	-	-	-
KA01	-	0.19	-	-
KA02	-	0.24	-	-
KA03	-	0.01	-	-
KA04	-	0.07	-	-
KA05	-	0.20	-	-
KA06	-	0.14	-	-
KA07	-	0.05	-	-
KA08	-	0.08	-	-
KA09	-	0.20	-	-
KA10	-	0.47	-	-
KA11	-	0.04	-	-
KA12	-	0.11	-	-
KA13	-	0.33	-	-
KA14	-	0.08	-	-
KA15	0.07	0.51	-	-
KA16	-	0.11	-	-
KA17	-	0.34	-	-
KA18	0.18	0.77	-	-
KA19	0.12	-	-	-
KA20	-	0.15	-	-
KA21	0.20	1.24	-	-
KA22	-	0.64	-	-
KA23	0.50	1.85	-	-
KA24	-	1.34	-	-
KA25	-	1.64	-	-
KA26	0.23	1.06	-	-
KA27	-	0.24	-	-
KA28	1.65	5.34	-	-
KA29	-	0.08	-	-
KA30	-	0.18	-	-
KA31	-	0.11	-	-
KA32	-	0.20	-	-
KA33	-	0.51	-	-
KA34	-	0.39	-	-
KA35	-	1.02	-	-
KA36	-	0.18	-	-
KA37	0.25	1.32	-	-
KA38	-	0.23	-	-
KA39	-	0.04	-	-
KA40	-	0.51	-	-
KA41	-	1.09	-	-
KA42	-	0.07	-	-

Origins (buying centres)	Destinations (factories)			
	Kagwe	Kambaa	Mataara	Theta
KA43	-	0.63	-	-
KA44	-	0.33	-	-
KA45	-	0.71	-	-
KA46	0.22	1.10	-	-
MTO1	-	-	0.24	-
MT02	-	-	0.08	-
MT03	-	-	0.02	-
MT04	-	-	0.14	-
MT05	-	-	0.18	-
MT06	-	-	0.18	-
MT07	-	-	0.27	-
MT08	-	-	0.05	-
MT09	-	-	0.19	-
MT10	-	-	0.28	-
MT11	-	-	0.32	-
MT12	-	-	0.45	-
MT13	-	-	0.18	-
MT14	-	-	0.19	-
MT15	-	-	0.09	-
MT16	-	-	0.16	-
MT17	-	-	0.15	-
MT18	-	-	0.02	-
MT19	-	-	0.22	-
MT20	-	-	0.27	-
MT21	-	-	0.14	-
MT22	-	-	0.32	-
MT23	-	-	0.18	-
MT24	-	-	0.05	-
MT25	-	-	0.24	-
MT26	-	-	0.06	-
MT27	-	-	0.34	-
MT28	-	-	0.38	-
MT29	-	-	0.34	-
MT30	-	-	0.14	-
MT31	-	-	0.21	-
MT32	-	-	0.18	-
MT33	-	-	0.46	-
MT36	-	-	0.23	-
MT37	-	-	0.85	-
MT38	-	-	0.38	-
MT39	-	-	0.14	-
MT40	-	-	0.28	-
MT41	-	-	0.03	-
MT42	-	-	0.05	-
MT43	-	-	0.91	-
MT44	-	-	0.18	-
MT45	-	-	0.18	-
MT46	-	-	0.49	-
MT47	-	-	0.32	-
MT48	-	-	1.43	-
MT49	-	-	0.90	-

Origins (buying centres)	Destinations (factories)			
	Kagwe	Kambaa	Mataara	Theta
MT50	-	-	0.44	-
MT51	-	-	0.25	-
MT52	-	-	0.35	-
MT53	-	-	0.29	-
MT54	-	-	0.76	-
MT55	-	-	0.35	-
MT56	-	-	1.04	-
MT57	-	-	1.96	-
MT58	-	-	0.42	-
MT59	-	-	0.66	-
MT60	-	-	0.92	-
TH01	-	-	-	0.01
TH02	-	-	-	0.16
TH03	-	-	-	0.12
TH04	-	-	-	0.06
TH05	-	-	-	0.05
TH06	-	-	-	0.22
TH08	-	-	-	0.21
TH09	-	-	-	0.09
TH10	-	-	-	0.01
TH11	-	-	-	0.02
TH15	-	-	-	0.05
TH16	-	-	-	0.09
TH18	-	-	-	0.21
TH19	-	-	-	0.18
TH21	-	-	-	0.06
TH23	-	-	-	0.06
TH24	-	-	-	0.17
TH25	-	-	-	0.22
TH26	-	-	-	0.38
TH27	-	-	-	0.15
TH28	-	-	-	0.23
TH29	-	-	-	0.23
TH30	-	-	-	0.25
TH31	-	-	-	0.22
TH32	-	-	-	0.40
TH33	-	-	-	0.23
TH34	-	-	-	0.37
TH35	-	-	-	0.36
TH36	-	-	-	0.28
TH37	-	-	-	0.35
TH38	-	-	-	0.24
TH40	-	-	-	0.30
TH41	-	-	-	0.67
TH42	-	-	-	0.36
TH43	-	-	-	0.32
TH44	-	-	-	0.30
TH45	-	-	-	0.50
TH46	-	-	-	0.30
TH47	-	-	-	0.35
TH49	-	-	-	0.09

Origins (buying centres)	Destinations (factories)			
	Kagwe	Kambaa	Mataara	Theta
TH50	-	-	-	0.60
TH51	-	-	-	0.61
TH52	-	-	-	0.55
TH53	-	-	-	0.79
TH54	-	-	-	0.35
TH55	-	-	-	0.28
TH56	-	-	-	0.27
TH57	-	-	-	0.30
TH58	-	-	-	0.55
TH59	-	-	-	0.46
TH60	-	-	-	0.26
TH61	-	-	-	0.85
TH62	-	-	-	0.73
TH63	-	-	-	1.07
TH64	-	-	-	1.93
TH65	-	-	-	0.89
TH66	-	-	-	0.16
TH67	-	-	-	1.46
TH68	-	-	-	2.42

-[a] A dash indicates the impossibility of certain buying centres for certain factories