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A MULTI-PERIOD LINEAR PROGRAMMING MODEL FOR OPTIMALLY SCHEDULING THE DISTRIBUTION OF FOOD-AID IN WEST AFRICA

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Julian Ray

August 1987

ACKNOWLEDGEMENTS

During the course of this thesis research, a number of people have assisted and advised me generously. In particular I would like to thank Charles Vandervoort of USAID who supplied the majority of the data used in this research, and without whose help, this research would have been impossible.

I would also like to acknowledge the help and guidance of my committee, and in particular, Dr. Bruce A. Ralston who dedicated a great deal of time and effort to make this research possible.

ABSTRACT

One of the major barriers to the use of African transportation systems as a medium for food-aid transportation is the washout of transport links during the rainy season. In this paper, the effects of the rainy season on the 1985 distribution effort are reviewed, and a planning model which accounts for rainy season effects in scheduling the transportation of food-aid is presented.

In particular, a multi-period storage and distribution linear programming model is developed. The model, which is one component of the Food For Peace Inland and Emergency Distribution System, determines the best use of existing transportation and storage facilities for food-aid distribution in Africa. Analysis of transport system and storage facility improvements are also discussed.

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CHAPTER 1

THE AFRICAN FAMINE OF 1984-85

1.1 Introduction

In 1984, sub-Saharan Africa experienced the most severe drought in its history.[1] The ensuing famine severely affected the economies of millions of inhabitants throughout sub-Saharan Africa. Many of these affected inhabitants were faced with the loss of livelihood or even life. The United Nation's Food and Agricultural Organization (FAO) listed 21 sub-Saharan countries as being most affected in terms of harvest shortfalls. By 1985, at the height of the drought, President Reagan announced a major relief initiative aimed at relieving the food stress occurring in Africa. In response, the United States shipped over 3 million metric tons (MT) of food to the African continent in the fiscal year (FY) 1984-85. This amount was almost 50 percent of the total food-aid delivered to Africa by the world donor community for that year.[2]

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[1]Bureau of Food for Peace and Voluntary Assistance, Evaluation of the African Emergency Food Assistance Program 1984-85 Synthesis Report, Washington, D.C.: Agency for International Development 20523, (1986). p. 1.

[2]Ibid. p. 4.

The success of the U.S. relief effort was, however, limited by waste of both food and capital resources resulting from inadequate planning for such a massive logistical problem. Moreover, barriers to the efficient and effective management of relief operations were manifest through a variety of economic, institutional, political, and environmental constraints.

This study uses the lessons learned in the last emergency to construct a suitable model for use in a possible future emergency. In particular, a linear programming (LP) model is developed to optimally schedule transportation of food-aid and calculate inter-period storage requirements over a large integrated multi-modal network which varies through time.

1.1.1 Scope of the 1984-85 Emergency

For many countries affected in the last emergency, drought and crop shortfall are recurring phenomena. In 1984, harvests were below average in nearly every sub-Saharan African country. For many of these affected countries this was the third, fourth or more consecutive year of drought.[3] The drought exacerbated a trend of declining crop yields for the Sahel region as a whole. A three percent drop in food production between FY 1981-82

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[3] Ibid. p. 1.

and FY 1983-84 was further worsened by a population growth rate of over three percent for the sub-Saharan region.[4] The result was an average eight percent <u>per capita</u> loss of food output over the same period.

An estimated 150-200 million persons out of a total 380 million (39-52%) within the affected regions were defined as being "at-risk".[5] Of the "at-risk" population, about 30 million were severely threatened by starvation and malnutrition.[6] Accurate data on the death rates are unavailable but are likely to be high. In Mozambique, for example, an estimated 100,000 people died of starvation in 1984.[7]

1.1.2 <u>Nature of the Response</u>

Africa imported over 12 million MT of food in FY 1984-85, of which 48 percent was non-commercial food-aid.[8]

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[4]World Bank, <u>Towards Sustained Development in Sub-Saharan Africa</u>, Washington, D.C.: World Bank, (1984).

[5]United States Department of State, Agency for International Development. <u>Report to the Congress</u>, Washington. D.C.: September 30, (1985).

[6]Bureau of Food for Peace and Voluntary Assistance. p. 2.

[7]<u>Africa News</u>, XXIV No. 4. February 25. (1985).

[8]Bureau of Food for Peace and Voluntary Assistance. p. 3.

However, this volume of food imports was not sufficient to curb the widespread effects of drought and famine. Critical estimates by the United States Department of Agriculture (USDA) and the United States Agency for International Development (USAID) indicated that an additional 4.5 million MT of food-aid was needed to relieve the food stress in the 1984-85 crop year. In response, the U.S. shipped over three million MT of food-aid of which almost two million MT were emergency food-aid; a 130 percent increase over the 1983-84 FY period. The total value of this aid was $1.08 billion of which 60 percent was direct emergency and grant assistance. Further assistance was provided by the Office of Foreign Disaster Assistance (OFDA) who granted $90 million for transportation and the Department of Defense (DOD) who granted $1.8 million in services. The private sector similarly mobilized resources. Approximately $125-200 million in emergency aid was donated by a variety of private and voluntary organizations.[9]

1.2 Barriers to the Distribution of Food-Aid

Many of the inefficiencies of the relief effort resulted from blocks and barriers affecting the

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[9] Ibid. p. 4.

distribution process.[10] Impeding food-aid distribution are political, economic, institutional, and environmental barriers.[11] The effects of many of these blocks and barriers could have been minimized through more effective management and coordination of the relief efforts. In particular, inter-organization communication was severely lacking.[12] The blocks and barriers constraining the relief efforts influence the distribution process at key points in the transportation network and in the viability of the transportation network as a medium for large-scale commodity distribution.

1.2.1 Transportation Infrastructure

Probably the most severe limitations to the effective distribution of food-aid are the barriers acting upon the transportation infrastructure. Constraints on the transportation of food-aid occur at the ports of

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[10]In the context of this thesis the term 'barrier' is defined as an obstacle which could be overcome. A 'block', however, is defined as an obstacle which is insurmountable, for instance, a closed border crossing as was the case between Nigeria and Chad.

[11]Ralston, B. A. and G. Harrison. Barriers to the Transportation of Food-Aid: A Study of the Sahel-Sudanic Zone, Transportation Center: The University of Tennessee, (1985). p. 1.

[12]Interview with Africa Technical Resources (AF/TR) Official at the State Department: Washington, D.C., May (1987).

disembarkation and in the transportation modes available for the distribution process.

Port Facilities: Port offtake rates are the rate at which goods can be loaded onto the inland transportation network at a port. The offtake rates for ports vary as a function of berth capacity, port facilities, and transport availability.

Low berth capacity and inappropriate priority structures at some ports in the 1984-85 emergency were responsible for delays in the relief effort. For example, 71,500 MT of food-aid were afloat at the port of Assab in Ethiopia in May 1985 waiting for berth.[13] Other ports experienced similar difficulties. Port Harcourt in Nigeria had three food-aid vessels waiting for berth in May 1985 and a five day waiting time was normal for the port of Djibouti.[14] These delays occurred because priority for port facilities was often given to commercial traffic.[15]

Once the food-aid was off-loaded other factors come into play. The rate at which the food-aid could be put

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[13]Unclassified USDA communique, Ref. Rome 13012.

[14]Ibid.

[15]Ralston and Harrison. p. 12.

onto the transportation network varied by port and mode. In many cases, the offtake rates were limited by the supply of trucks. For instance, in the Nigerian ports, the primary factors governing the offtake rates were the availability of trucks and the time required to make a round trip to the inland distribution centers.[16] Shortages of rolling stock and low priority were the usual causes for low rail offtake rates.

Low offtake rates resulted in the accumulation of surplus food-aid at the ports. Many ports had backlogs of food-aid waiting for inland distribution. Warehouse facilities tended to be inadequate or unavailable; thus, food-aid was improperly stored, causing wastage. For instance, the port of Assab in Ethiopia had 76,000 MT of food-aid on the docks in May 1985, and a 40 minute rain at Assab led to the spoilage of 7,000 MT of grain.[17] Even when storage was available, requirements often outran capacity or, alternatively, was reserved for commercial

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[16]Carman, J. C. and Vandervoort, Food Aid Logistics Problems in West Africa, Possible Solutions, and Recommended Actions: Report to the TEAF Transport Assessment Team, Interagency Task Force on the African Emergency, Washington, D.C.: Agency for International Development, (1985). p. 9.

[17]Ralston and Harrison. p. 12.

goods.[18] In some cases food-aid delivered in 1985 is still waiting to be transported inland.[19]

Road Transport: Highways and roads were the primary mode of transportation for the distribution of food-aid in the last emergency.[20] Two major limitations affect the efficiency of inland distribution via the road network. First, economic barriers limit the availability of transportation, and, secondly, inadequate and seasonable road networks reduce the accessibility of certain affected areas.

Food-aid transported by road often depends upon the profitability of such enterprise for the private trucking firms concerned. In many cases, the supply of trucks was artificially limited by inappropriate governmental pricing policies or competition for transportation of local commercial harvests and other domestic requirements.[21] In other cases, high transportation costs were incurred as a result of: (1) slow turn-around time for the trucks at both ports and inland destinations; (2) low availability

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[18]Ibid. p. 12.

[19]Op. Cit., note 12.

[20]Ralston and Harrison. p. 14.

[21]Carman, J. C. and C. G. Vandervoort. p. 1.

of truck spare parts (in particular tires); and (3) the cost of 'payoffs' at border crossings and local road checkpoints.[22] This is emphasized from the following quote taken from a communique:[23]

> It is estimated that a $100 bonus ($3 per ton) would be sufficient to induce truck drivers to make their return journey as rapidly as possible. This is in addition to the regular bonus of $200 that must be paid to compensate for the cost of black market tires and parts. Furthermore, the cost of facilitating the police inspection at checkpoints varies between $6 and $13 per checkpoint, with a total cost per trip of about $200.

Without donor support, the economic burden of such extraneous transport costs would reduce the profit to be gained by truckers, thus effectively limiting the supply of trucks. It was found, in many cases, that bonuses paid by the donors to truckers were sufficient to maintain the required number of vehicles.

The efficiency of road transportation is severely limited by environmental conditions. The road networks of the recipient countries are usually not well developed and vary by season:

> The road networks in recipient states are usually not as well developed. While roads between some major cities may be passable in all seasons, during the rainy season, roads serving remote areas, where food is usually most needed, are often negotiable only by four-wheel drive trucks of no more

[22]Ibid. p. 6.

[23]Communique. Ref. Rome 13012.

than 7 to 10 ton capacity. In some cases, roads become totally impassable during part of the rainy season. In the most severe cases roads are impassable year round.[24]

Other environmental conditions further exacerbate the debilitating effects of the rainy season: river crossings act as bottlenecks, effectively reducing the capacity of the road as a whole; steep gradients make certain roads difficult to negotiate; and high altitude in Ethiopia leads to freezing conditions.

Rail Transport: For the most part, West African railways are in poor condition.[25] Deterioration and neglect of rail facilities has left a series of poor quality, unconnected railroads. Food-aid transportation by those rail facilities that are available face problems that are usually political in nature or result from shortages of available money and supplies: (1) shortages of rolling stock affect most of the railways in the sub-Saharan region; (2) railcars are often used as temporary storage facilities rather than as transport vehicles; and (3) low priority is usually given to food-aid, governments preferring instead to move construction materials or war materiel. Political insurgencies can, furthermore, make

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[24]Ralston and Harrison. p. 15.

[25]Ibid. p. 12.

travel by rail unsafe as in the Massab-Assab railway in Ethiopia.

As with roads and highways, environmental factors can severely limit the carrying capacity of an economically viable railway. Heavy rainfall can flood tracks, wash out bridges, and make sections impassable.

Airlifts: In the 1984-85 emergency, some food-aid had to be delivered by military airlift. Some areas are so inaccessible that air transport is the only viable means. In other cases, the normal transportation routes were either impassable or too slow to satisfy demand within the time required.

Air transport is both costly and inefficient. The relative payload of air transports makes the cost-per-ton price for delivery far greater than that for other modes. The money spent on an airlift could, in some cases, be better spent on upgrading or augmenting a country's surface transportation.[26] It should, therefore, be avoided wherever possible.

1.2.2 Political Intervention

The efficient and effective distribution of food-aid is hampered by political intervention. Intervention of

[26]Ralston and Harrison. p. 18.

this sort takes three forms: barriers to distribution, blocks to transportation, and, mismanagement of resources.

Barriers to Distribution: Ralston and Harrison identified several reasons why relief efforts are frustrated by African governmental intervention.[27]

1. African governments often lack commitment to the food aid relief effort because their political interests lie in areas other than the alleviation of human distress.

2. When food-aid does arrive it is given low priority at ports and on railways.

3. In some instances, recipient governments are often reticent to ask for help or even admit to food shortage. Many regimes believe this is an admission of political failure that could lead to their downfall.

4. Governments are usually unwilling to commit scarce resources to food-aid distribution, particularly military resources. In many states, the military could be more active -- especially in secondary distribution.

5. Check points run by military and local police are common. These delay delivery and increase transportation costs.

These barriers, which often result from inefficient, understaffed and corrupt government agencies, severely hamper the effectiveness of relief efforts.

Political Blocks: There are two types of political blocks to the transportation of food aid. Firstly,

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[27]Ibid. p. 2-5.

military insurgencies limit transportation options by closing links or making them too dangerous to traverse. Parts of Ethiopia, Chad, and Sudan are inaccessible because of security problems. An AID official in Nairobi estimated that over two million people in Ethiopia were cut off from the relief effort because of fighting.[28]

Secondly, political disagreements between African states can frustrate relief efforts. The transportation network can be divided into two types: (1) that part which lies within "corridor" states (i.e., countries which do not have a major food crisis and are being used primarily as transportation corridors); and (2) that part which lies within recipient countries (Figure 1-1). Some states such as Chad and Mali are landlocked and must, of necessity, rely on the goodwill of neighboring corridor states for a continued supply of food-aid, or for that matter, any goods shipment. International disagreements occur. Until the Nigerian coup of August 1985, for example, Chad could not use Nigeria's roads or ports because of the Lagos government's dislike of the regime in N'djamena.[29] The ability to cross international boundaries must, then, be viewed as a privilege which could be quickly revoked. Alternative routes, if any, must then be chosen.

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[28]Ibid. p. 4.

[29]Ibid. p. 4.

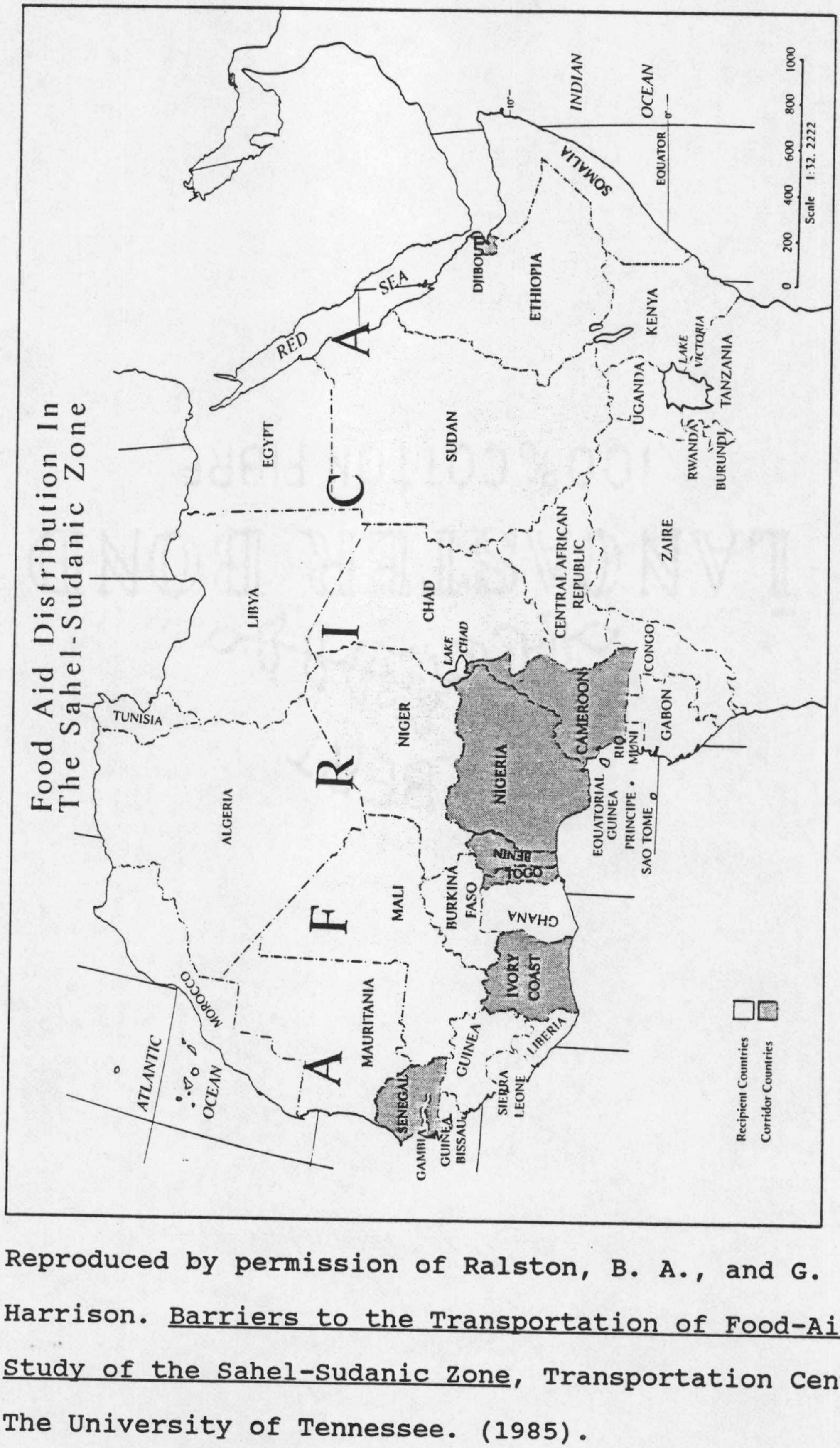

FIGURE 1-1

Food-Aid Distribution in the Sahel-Sudanic Zone.

Reproduced by permission of Ralston, B. A., and G. Harrison. Barriers to the Transportation of Food-Aid: A Study of the Sahel-Sudanic Zone, Transportation Center: The University of Tennessee. (1985).

<u>Mismanagement and Coordination:</u> In the aftermath of the 1984-85 emergency, criticism from within USAID itself,has been levelled at many of the agencies involved including its own relief efforts. This criticism is largely concerned with the allocation of resources within the agencies. In particular, USAID has been criticized as being understaffed and generally lacking in management resources capable of coping with a large logistics situation.[30]

Poor coordination also occurred between the donor organizations and the recipient countries themselves. The degree of coordination among the donors and recipients varied. The strongest ties existed between the donors and the states of Chad, Niger, and Mali. Here, the donors and recipients met regularly to "share information and cooperate in firming up analysis and assessment of need".[31] The weakest links existed between the donors and Sudanese officials.

Many donor organizations were involved in the 1984-85 emergency, but little coordination or cooperation among them existed. Many of the problems attributed to the overcrowding of port facilities were due, in part, to

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[30]Bureau for Food for Peace and Voluntary Assistance. p. XXIV.

[31]Ibid., p. 13.

ineffective coordination and control over the destinations of supply vessels and the scheduling of food deliveries. As a result food aid arrived too late, too early or even at the wrong port, adding to the congestion already present.[32]

1.3 Lessons Learned

Guidelines within five areas of concern have been identified by the Bureau for Food for Peace and Voluntary Assistance with reference to possible future emergency food-aid programs. The major areas of concern for which guidelines have been developed include:[33]

1. Pre-planning and preparation for future emergencies.
2. Identification of emergencies.
3. Preparation to respond to an identified emergency.
4. Ability to implement a planned response.
5. Ability to monitor and evaluate results.

The pre-planning stage is recognized by USAID as being crucial to the success of future food assistance programs. The notion of pre-planning incorporates the

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[32] Op. Cit., note 12.

[33] This section is a condensed version of the recommendations made in pages 42-81 of in Bureau of Food for Peace and Voluntary Assistance. (See footnote 1).

consideration of: (1) fundamental issues such as basic decision criteria, (2) effective methods of intervention, (3) the appointment of administrative personnel, and (4) the collation of data for early warning capability. In effect, it is ensuring that in the face of a future food crisis, there is an efficient set of management tools available for a timely response.

One of the requirements of the pre-planning stage is the development of a series of decision support tools capable of enhancing administrators' abilities to solve large complicated logistical problems. In particular, the decision tools should be able to do the following:

1. Provide a means whereby a central planning organization can effectively and efficiently schedule arrivals of food- aid to areas of food stress.

2. Provide a means of coordinating food-aid logistics between donor organizations.

3. Provide administrators with likely storage requirements and locations on a given network.

4. Provide a means of updating existing plans in light of monitored information.

5. Provide administrators with marginal economic information on the network and its characteristics thus identifying areas of greatest investment potential.

These tasks are accomplished via the development of a decision support system (DSS) which incorporates a set of database management tools, a LP driver, a LP Solver, and a report writer. A LP model is constructed to optimally schedule deliveries of food-aid to areas of demand over a multi-period planning horizon, while simultaneously calculating inter-period storage requirements. The database used by the model must be flexible to allow variations in the network characteristics during different periods (e.g., wet and dry season or monthly variation) and to incorporate variations in storage facilities within the network.

The model developed in this study is the part of the FIELDS system being developed at The University of Tennessee, Knoxville, designed and developed for USAID by Dr. Bruce Ralston and Julian Ray in conjunction with Charles Vandervoort of Food for Peace and Voluntary Assistance (USAID).[34] The role of the FIELDS DSS is to provide a composite series of logistical support models for planning food-aid distribution.

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[34]Food for Peace Inland and Emergency Logistics and Distribution System.

CHAPTER 2

DEVELOPING A MULTI-PERIOD LINEAR PROGRAMMING MODEL

The model developed in this study belongs to a class of linear programs called network flow models. In particular, this model represents the development of a single-commodity transportation model on a capacitated network. The model developed here incorporates a multi-period planning horizon and capacitized storage at some nodes. These extensions to the general transportation model are derived from LP models that have, heretofore, been used to optimally schedule reservoir storage and release.

2.1 The Network

Before presenting the LP model, it is necessary to define the basic concepts of a network graph. In general we can describe a network in terms of nodes, arcs, and flows.[35] Using this nomenclature we can simplify the complexities of the West African transportation network and reduce the characteristics to a matrix format suitable for use in mathematical models.

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[35]Garrison, W. "Connectivity of the Interstate Highway System," Papers of the Regional Science Association, 6, (1960). p. 121-137.

Nodes: Nodes are points in geographic space. More, specifically, we can identify nodes as locational origins and/or destinations of any form of interaction.[36] In this study, nodes are treated as vertices on the network graph which act as either supply points, storage locations, transportation hubs, or demand points. The demand nodes are of special interest in the food-aid distribution system. This study is concerned with the primary distribution of food-aid (i.e., the transportation of food-aid from supply nodes to inland distribution centers). In this case, the demand associated with any node represents the amount of food-aid required in the immediate locale; i.e., not all of the food-aid demanded is assumed to be required at the demand node per-se. The further distribution of food-aid from the demand nodes to the surrounding hinterland constitutes the secondary distribution and is beyond the aims of this model.

It should be noted that in a multi-period model such as this, demand nodes could also be areas of local supply of food-aid at different periods in the planning horizon.

Arcs: Arcs are treated as a simplified form of the original transportation route. Each arc is unique and has the following characteristics: (1) a single origin; (2) a

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[36] Lowe, J. C. and S. Moryadas. The Geography of Movement, Boston: Houghton Miffin Co., (1975). p. 81.

single destination; (3) a single mode of transportation; (4) a maximum volume of flow (which may be infinite); and (5) distance and cost values for traversing it in any time period. Arcs can be either one-way or bi-directional, although if bi-directionality is assumed, the cost of traversing an arc is constant for both directions.[37]

Flows: Interaction between nodes is treated as flows along arcs. The total volume of flow is a multiple of the flow units. In this case, the flow unit is 1,000 metric tons (MT) of food-aid.

2.2 Linear Programming and Transportation Problems

There is a tradition of using LP techniques to solve large scale transportation problems.[38] The use of LP in problem solving dates back to 1947 when George Dantzig developed the Simplex Algorithm, and since then, has become widely used in the fields of management and decision analysis. There are many advantages in using such techniques. First, if the problem is mathematically

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[37] In the cases where constancy in both directions is not a valid assumption, the model can be "tricked" by assuming an (i,j) and a (j,i) pair of arcs which have separate characteristics. In such a case, both arcs are one-way.

[38] See for instance: Steenbrink, P. A. Optimization of Transport Networks, Bristol: John Wiley and Sons. (1978). p 9-10.

feasible, an optimal solution is guaranteed. Secondly, commercial LP codes enable large complex problems to be solved efficiently on both micro and mainframe computers. Thirdly, marginal economic information is available through interpretation of the dual as a set of shadow prices.[39] Thus, information regarding areas of greatest potential investment is readily available by examination of the dual interpreted as a set of shadow prices.

Cost Curves: The only restriction made by LP models is that both the objective function and the constraints be linear. This poses a problem in transportation modeling as cost functions are often non-linear (e.g., economies of scale are typically U-shaped). However, this problem can be overcome by approximating the cost curve with a linear function or using stepwise cost functions or other non-linear techniques.[40]

In this model, linear cost functions can be validly assumed because the U.S. Government pays cost-per-unit prices for transportation of food-aid. Thus, the cost for

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[39] See for instance: Bradley, S. P., A. C. Hax, and, T. L. Magnanti. Applied Mathematical Programming, Reading, Massachssets: Addison-Wesley Publishing Company. (1977). Chapter 4, p. 157-192.

[40] See for instance: Bradley, Hax, and Magnanti. Chapter 13. p. 580-589.

transporting food-aid overseas is linearly related to the distance over which it travels.

Supply and Demand: Network flow models generally involve the distribution of a homogenous product from origins to consumers. It is assumed that total supply and demand are known and that all demand can be met. The product is routed through the transportation network so that the total cost of transportation is minimized. In this case, supply nodes are either ports or inland nodes where local surplus food is available. Demand nodes are secondary distribution centers. Both supply and demand are assumed to change over time (i.e., from one period to the next) and all demand can be supplied either by normal transportation methods or airlift.

2.3 Developing a LP Model

LP models are typically comprised of two parts: the objective function, a mathematical interpretation of the decision criterion; and the constraints, which reflect the supplies and demand of the distribution system and the physical limits of the distribution network.

2.3.1 The Objective Function

The ultimate aim of this model is to satisfy all the demand while simultaneously incurring the lowest possible transportation costs. Thus the cost for all flows along all arcs in all time periods are minimized as well as are the storage costs and the costs of airlift for all time periods.

2.3.2 The Constraints

Five types of constraints are used in this model: port offtake, demands, storage availability, shipping (arc) capacities, and conservation of flow.

Port Offtake: One of the major limitations to the distribution of food-aid is the rate at which food can be moved inland from African ports. For each port in the database, there is a maximum capacity by mode which represents the volume of food-aid which can be loaded onto the relevant mode per month. The capacity may vary by time period reflecting local characteristics such as busy periods during harvest, delays caused by bad weather, and changing economic conditions such as increased truck supply. An example of such offtake is shown in Table 2-1. The offtakes shown in Table 2-1 are actual offtake as opposed to maximum offtake rates.

Demand Constraints: The demands associated with any node represent the estimated volume of food-aid required

TABLE 2-1

Offtake Rates for Selected West African Ports (1985).

Country	Port	Mode	Offtake Rate (MT/Month)
Senegal	Dakar	Rail	15,000
Ivory Coast	Abidjan	Rail	30,000
		Road	2,500
Togo	Lome	Road	18,500
	Lome	Rail	15,000
Benin	Cotonou	Road	17,000

Source: Unclassified U.N. Document. World Food Programme - African Emergency Weekly Report No. 18 On Food-Aid Shipment to the Most Affected African Countries, Ref. Rome 12465. (May 1985).

for secondary distribution from that node.[41] Volumes are in thousands of metric tons per month.

For any time period, a minimum feasible volume of food-aid is estimated that must be satisfied either by normal transportation routes or by airlift. Examples of such data are given in Table 2-2.

Storage Availability: Any node within the network can be used as a location for potential storage. The

[41]Estimated volumes of demand are calculated by empirical data collected by agents in the field together with forecasts on harvest yields and climatic data. Potential demand is estimated by FEWS (Famine Early Warning System) which uses a variety of sociological and climatic data to identify areas of likely food-stress.

TABLE 2-2

Estimated Monthly Cereal Requirements for Sudan From May-November (1985).

Region	Affected Population	Monthly Cereal Requirements (MT/Month)
Darfur	2,500,000	30,000
Kordofar	2,500,000	30,000
Central	1,300,000	17,000
Eastern	1,100,000	13,200
Northern	150,000	1,800

Source: Unclassified U.N. Document. World Food Programme - African Emergency Weekly Report No. 18 On Food-Aid Shipment to the Most Affected African Countries, Ref. Rome 12465. (May 1985).

limit for storage at each node is set for each time period to reflect the availability of such facilities. A cost associated with storing a single MT is also given. It isassumed that the cost of storage is a linear function and that all food-aid stored at any node in a single time-period is used in the next time period (i.e., acts as local supply). The volume and cost of storage facilities is empirically derived.

Shipping Capacities: Each arc in the network has a maximum potential flow which acts as a strict upper bound for that arc. This upper bound may vary between zero (no flow is allowed) to infinity. An implicit lower bound of zero exists on all arcs. The shipping capacity can be reset each time period to reflect temporal and seasonal changes in the network.

In the cases where bi-directional flow is assumed, the shipping capacity acts as a fixed limit in both directions.

Conservation of Flow: Conservation of flow constraints are necessary to ensure correct linking of the individual time periods across the complete planning horizon. Each node in the network has a conservation of flow constraint to ensure that the supplies to and demands from each node across all time periods equals the aggregate demand (or supply) at each node (i.e., that no food-aid is accidentally lost or generated by the model).

2.4 Model Formulation

Formulation of this LP model centers around the constraints and objective function already discussed.

2.4.1 Notation and Decision Variables

The notation and decision variables used in this model are as follows:

$\{i\}$ = the set of all nodes where $i = 1,2,\ldots,I$.

$\{j\}$ = the set of all arcs where $j = 1,2,\ldots,J$.

$\{k\}$ = the set of all modes where $k = 1,2,\ldots,K$.

$\{t\}$	= the planning horizon where t = 1,2,...,T.
ARC_{jt}	= Volume of flow along arc (j) in time period (t).
OFF_{ikt}	= Aggregate offtake from port (i) by mode (k) in time period (t) for all (j).
DEM_{it}	= Demand at node (i) in time period (t).
AIR_{it}	= Volume of airlift required at node (i) in time period (t).
$STOR_{it}$	= Volume stored at node (i) in time period (t).
A_{ijt}	= 1 if arc (j) enters node (i) in time period (t). -1 if arc (j) leaves node (i) in time period (t) and 0 otherwise.
C_{jt}	= Cost per MT of flow along arc (j) in time period (t).
AC_{it}	= Cost per MT of airlift at node (i) in time period (t).
SC_{it}	= Cost per MT of storage at node (i) in time period (t).
$Scap_{it}$	= Capacity of storage facilities at node (i) in time period (t).
$Acap_{jt}$	= Shipping capacity of arc (j) in time period (t).

2.4.2 Variables and Dependencies

The decision variables define the columns of the LP tableau. In this model, the columns of the tableau consist of three types of decision variables: arcflows (ARC), airlifts (AIR), and storage (STOR).

<u>Arc Flows:</u> Each arc in the model has a variable associated with it for each time period. If bi-directionality is assumed, then a second variable (its "twin") is also written into the tableau. Thus an ARC variable exists for each arcflow-time-direction combination. The dependencies imply that each ARC variable must be linked to every row constraint by a +1, -1, or a 0. If any arc (j) enters a node (i) (i.e., node (i) is a destination), then a positive value is written. If any node (i) is an origin, a negative value is written as flow, if assigned, will always leave the node along that arc. If an explicit shipping capacity is associated with that arc, then the ARC variable must be linked with the appropriate row constraint. Similarly, the ARC variable must be linked with demand and conservation of flow constraints where appropriate.

The cost associated with each ARC variable reflects the cost-by-distance value for traversing the arc. In the case of twins, the arcs have the same cost.

Each bi-directional arc has the dependencies reversed for its twin. Thus, if an arc enters any node (i) its dependency coefficient is a +1 and the dependency coefficient is -1 for its twin. Each arc for every time period must be examined in this way to ensure that a true representation of the network is described in the LP model.

Airlifts: The second set of variables in the objective function describe the amount of airlift necessary to solve the given problem. Each node (i) that has a strictly positive demand for food-aid in any time period (t) has an AIR variable. In essence, the AIR variables operate as unrestrained arcs with a high cost. Each "AIR-arc" has a single destination but no origin. AIR arcs ensure that all demand can be met for any given node in any given time period even if the surface transportation routes cannot facilitate the food-aid delivery. The cost associated with each AIR arc reflects the cost for airlifting food-aid into the node.

The dependencies associated with each AIR variable imply that each node (i) with an AIR variable in any time period (t) be linked with a positive coefficient to the demand-time constraint and the conservation of flow constraint for that node.

Storage: The last set of decision variables in the objective function determines the use of storage facilities at each node. A STOR variable exists for each node-time combination where a storage capacity exists. The costs associated with each STOR variable reflect the storage costs at each node.

The dependencies associated with each STOR variable interact with the demand, storage, and conservation of flow constraints. For any time period (t), each STOR variable has a negative coefficient with the demand for that time period, a positive coefficient for the demand at the following time period, and a positive coefficient for the storage constraint. At the end final time period the STOR variable must also be linked to the conservation of flow constraints to ensure that all storage is used.

2.4.3 Row Constraints

Row constraints fall into one of five categories: port offtake, demands, storage capacities, shipping capacities, and conservation of flow.

Port Offtake: A single row in the LP tableau exists for every port-by-mode-by-time combination which has a non-negative offtake rate (the offtake rate could be set to zero in any time period). The constraint states that the flow leaving node (i) which is a port along all arcs (j) of mode type (k) in time period (t) must be less than or equal to the maximum offtake rate for that port-mode-time combination. The general form of the constraint is

$$\Sigma_j \Sigma_k \; ARC_{jt} A_{ijt} \leq OFF_{ikt} \qquad \text{for all (i) and (t).}$$

It should be noted that all arcs leaving ports are considered to be one-way; thus, the coefficients for each A_{ijt} value is -1 in this case.

Demands: A demand constraint exists for every node-time combination in the network. The demand associated with any node (i) in time period (t) must be at least equal to the flow of food-aid into the node by all arcs (j) plus any airlift associated with the node (i), plus any storage at (t-1), minus any flow leaving the node, minus any storage associated with the node. The general form of the constraint is

$$\Sigma_j \; ARC_{jt} A_{ijt} + AIR_{it} + STOR_{it-1} - STOR_{it} \geq DEM_{it}$$

for all (i) and (t).

It should be noted that the value of demand associated with any node-time combination could either positive, negative or zero. In the first case, the node acts as a "sink" for food-aid. In the second case, the negative value indicates an area of local supply of food-aid. In the last case, the node has neither demand for or supply of food-aid for that time period.

Shipping Capacities: Each arc in the network has a maximum upper bound on the flow associated with it in any time period. If the arc is unconstrained (i.e., an infinitely high shipping capacity), the shipping capacity constraint is omitted. In general there is a row constraint for every explicitly defined shipping capacity along any arc (j) in time period (t). The general form of the constraint is

$$\mathrm{ARC}_{jt} \leq \mathrm{Acap}_{jt} \qquad \text{for all (j) and (t).}$$

Storage Capacities: A row constraint must be defined for every node (i) which has storage facilities available at time (t). This constraint limits the volume of food-aid which is stored at each node to no more than the maximum allowable storage at that node in any time period. The general form of the constraint is

$$\mathrm{STOR}_{it} \leq \mathrm{Scap}_{it} \qquad \text{for all (i) and (t).}$$

Conservation of Flows: The above four sets of constraints define a block-structured tableau where each block represents the operational constraints for each time period (Figure 2-1). The conservation of flow constraints operate as linking rows across all time periods and ensures that the model maintains integrity from one time period to the next.

A conservation of flow constraint is required for every node in the network. The constraint states that for any node (i), all flow into and out of the node by arcs (j) over all time periods (T), plus the sum of all airlifts required over all time periods (T), plus any initial storage where (t = 0), minus all flow leaving the node in every time period along all arcs (j), minus any storage at the final time period (t = f), minus the sum of all demands associated with node (i) for all time periods (T) must be equal to zero. This ensures that no food-aid is lost or generated by the system. The general form of the constraint is:

$$\Sigma_j \Sigma_t (ARC_{jt} A_{ijt} + AIR_{it}) + STOR_{it=0} - STOR_{it=f} - \Sigma_t DEM_{it} = 0$$

for all (i).

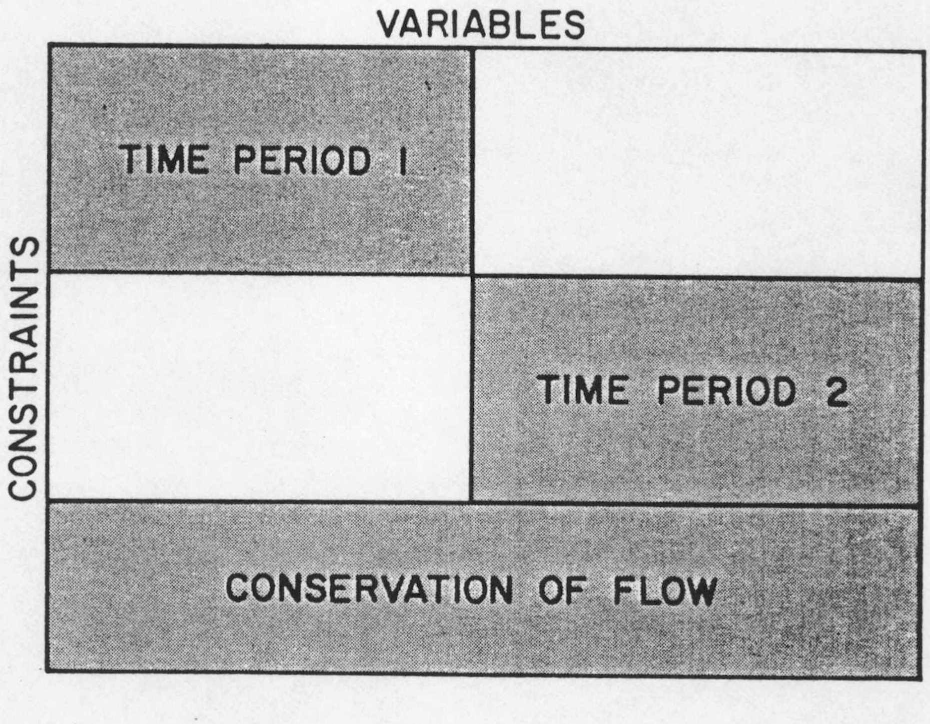

FIGURE 2-1

Primal Block Structured LP Tableau for a Two Period Problem.

2.4.4 Formulation

The LP problem can now be stated:

(1) $\text{Min } \Sigma_j\Sigma_t \; ARC_{jt}AC_{jt}A_{ijt} + \Sigma_i\Sigma_t \; AIR_{it}AC_{it} + \Sigma_i\Sigma_t \; STOR_{it}SC_{it}$

Such that:

(2) $\Sigma_j\Sigma_t \; ARC_{jt}A_{ijt} \leq OFF_{ikt}$ for all (i) = port and (t).

(3) $\Sigma_j \; ARC_{jt}A_{ijt} + AIR_{it} + STOR_{it-1} - STOR_{it} \geq DEM_{it}$ for all (i) and (t).

(4) $\Sigma_j\Sigma_t(ARC_{jt}A_{ijt} + AIR_{it}) + STOR_{it=0} + STOR_{it=f} - \Sigma_t DEM_{it} \geq 0$ for all (i).

(5) $ARC_{jt} \leq Acap_{jt}$ for all (j) and (t).

(6) $STOR_{it} \leq Scap_{it}$ for all (i) and (t).

The objective function (1) minimizes the sum of all costs incurred during the transport and storage of food-aid over the planning horizon. The offtake rates for each port by mode for any time period is set by constraint (2). The demands for food-aid in any time period for any node are set by constraint (3). As noted above, the right-hand side of (3) could be negative, zero or positive reflecting local supply, no demand, and local demand respectively in any time period. Constraint (4) ensures conservation of flow over the planning horizon. Constraint (5) restricts shipping capacities on the arcs by time-period while (6) limits the volume of storage at any node in any time period.

2.5 Solving the Model

The maximum dimensions of the model are 2t(m + n) variables (m = arcs, n= nodes, t = time periods) by 3nt + 2nt + n constraints. The main constraint on the size of the problem that could be solved is the capacity of the LP solver. The formulation described above rapidly becomes large with relatively small increases in the network.

As the LP model is the center of a personal computer (PC)-based decision support system, a commercial LP code capable of taking batch input and large problems is required. LP83[42] was chosen as a suitable code because this software is capable of solving large problems on a PC. Data input is constructed using a pre-processor (LP driver).

2.6 The Pre-Processor

The pre-processor is a computer program written in Microsoft C which is used to interpret raw data into a LP model of the type discussed above. Three sets of data are required by the pre-processor: information on the state of ports in the network, information on the demands and storage availability at nodes in the network, and data regarding the current state of the arcs.

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[42]LP83 Version 5.00, Sunset Software, San Marino, California.

All the data used in the FIELDS DSS (with the exception of storage data) are readily available from sources within USAID.

2.6.1 Data Files

The three data files contain all the information required by the pre-processor to construct an "intelligent" interpretation of the network. Each time period is delimited by an ENDDATA card and successive time periods can be "stacked" one on top of another. All volumes are in MT per month, and all costs are in dollars per MT.

Port Data: The ports data file consists of a port name followed by the maximum feasible aggregate offtake rate by mode for that time period. Allowable modes are RAIL, ROAD, and WATER. In the cases where a mode is unavailable a flag is entered indicating such. A -1 value in the data files indicates this. When a "mode-unavailable-flag" is encountered, no constraint is written in the LP tableau.

The advantage of using a "mode-unavailable flag" are that the marginal returns for an offtake at a port which is available but not used, can be assessed. For example, the port of Lagos, Nigeria, is unused because the railroad is extremely inefficient. However, by including this port in the database, the marginal returns for using the port, if it could be made viable, may be ascertained.

Node Data: The nodes data file consists of a node name followed by a series of values representing the minimum feasible demand (or, if negative, the maximum feasible supply), maximum physical storage capacity, cost of storage, and cost of delivery by airlift if required. As above, a -1 in the storage capacity fields represents a "storage-unavailable-flag". This is used so that marginal economic information can be found on nodes with a zero volume of storage.

Arcs Data: The arcs data file consists of seven data fields: (1) the name of the origin node; (2) the name of the destination node; (3) the mode; (4) the distance (in km); (5) the cost per km of shipment along the arc; (6) a maximum physical limit on shipment along the arc; and (7) a flag representing whether or not bi-directionality is assumed.

From this information, the pre-processor can reconstruct the network and thus construct the appropriate LP tableau. The data file produced by the pre-processor is used as input to the LP solver. The solution of the LP is written to a file and interpreted with a report writer which is described in the next chapter.

CHAPTER 3

THE REPORT WRITER

The report writer in the FIELDS DSS must be capable of performing two major tasks. The first is to interpret the output of the LP model, and the second is to provide an interface between the model and the raw data regarding the network. In this way, the user of the DSS is provided with sufficient, easily interpreted information regarding the use of the network rather than a mass of uninterpreted raw LP output.

3.1 LP Output Interpretation

The major advantage of using a report writer is that it requires little knowledge of LP techniques on the part of the user. Primal and dual interpretation can be accomplished and presented as a series of tables that are easy to understand, while graphic techniques can be used to present flow data and network information. The report writer described below presents a series of summaries in tabular form followed by graphic portrayal of the current state of the network in each time period. The summaries are disaggregated by individual time periods followed by a general summary covering all time periods.

Five types of summary are produced: (1) port summaries, (2) node summaries, (3) storage summaries, (4) arc summaries, and (5) a general summary. Each summary incorporates relevant primal and dual information.

3.1.1 Primal Interpretation

The LP output consists of the current value of each variable and constraint in the solution to the model. The solution value of an ARC_{ijt} variable, for example, gives the volume in MT of food-aid flowing along arc (j) from node (i) in a given time-period. Similarly, the AIR_{it} variables determine the volume of food-aid requiring airlift into each node (i) in time period (t), and the $STOR_{it}$ variables determine the volume of storage at any node (i) in time period (t).

The value of the constraints in the solution can provide valuable information on the state of the network. Arcs which are constrained (i.e., have flows along them equal to their shipping capacities) can be reported. The ports where offtake rates are limiting supply (i.e., the offtake rates are constrained) can be identified, and, similarly, nodes where storage facilities are filled to capacity can be identified.

From this primal information, the solution can be reconstructed. The amount of food-aid required at each port in a given time period can be determined as well as the routes of the network used for inland distribution. Over the whole planning horizon, an aggregate picture can be constructed of the distribution requirements and a time-table for optimally scheduling the arrival of food aid at each port and each node can be derived.

3.1.2 Dual Interpretation

The dual values of the LP solution provide valuable economic information on the costs of each variable and constraint in the model. The interpretation of the dual depends on the type of variable and constraint.

The dual values for variables (also called the reduced costs) indicate the required reduction in cost for using one more unit of that variable at the margin. Variables which are in the solution have a reduced cost of zero. ARC variables, for instance, have a reduced cost equal to the decrease in transportation cost required to make that arc economically viable (or, alternatively, the increase in costs that would occur if that arc is used). The reduced cost for STOR variables similarly show the decrease in storage costs required before the storage facilities at any node could be used.

The dual values for constraints (also called the shadow prices) indicate the savings to be made by altering the value of the constraint. This provides valuable marginal economic information on the state of the network and indicates areas for greatest potential investment. For instance, the dual cost on a shipping capacity constraint would indicate the decrease in cost that would be derived if the shipping capacity were increased by one more unit.

Offtake: The shadow prices for port offtake constraints indicate the savings to be made by increasing the port offtake by one more unit in a given time period. If the offtake rate is constrained, the shadow price will show the decrease in cost of the overall solution if the offtake rate could be increased by one more unit. That is, the ports where greatest benefit will be derived if investment was to occur in the port offtake rates.

Demands: The shadow prices on the demand constraints indicate the cost of supplying the next MT of food-aid to that node in a given time period. This serves as an indicator of the cost of supplying a node with food-aid. The nodes which are most expensive to serve can be determined (i.e., least accessible). An examination of these values between different time periods will indicate areas of possible distribution difficulties and, therefore, areas where investment in accessibility will derive the greatest benefit.

Shipping Capacities: The shadow prices associated with shipping capacities represent the savings to be made by increasing the allowable volume of flow along the arc. If the arc is constrained, the shadow price will show the savings to be made by investing in the arc carrying capacity. Those arcs with the greatest value of shadow prices indicate areas of greatest potential investment in the network.

3.2 Summaries

The report writer constructs a series of tables for each time period. Each table incorporates primal and dual information to provide the user with a fully interpreted report on the model. The example summaries given below are from a test run of the FIELDS DSS on West African data from 1985.

Port Summary: The port summary reports the value of all offtake by mode for each port in a single time period. The capacity and shadow price are also given. Table 3-1 is a sample of such a port summary.

Table 3-1 summarizes the offtake rates for various West African ports in the first of a two period planning horizon. The Offtake represents the required volume of food-aid to leave each port in the first time-period by the mode indicated. The current offtake capacity is

TABLE 3-1

Sample Port Summary

Port Summary

Model: FIELDS III Time Period 1 of 2

Port	Offtake	Mode	Capacity	Dual Cost
Abidjan	10554.00	RD	25000.00	$0.00
Abidjan	12500.00	RL	15000.00	$0.00
Calabar	10413.00	RD	20000.00	$0.00
Cotonou	12000.00	RD	12000.00	$13.41
Cotonou	12500.00	RL	20000.00	$0.00

reported along with the dual cost.

In the first case, the offtake from Abidjan by road is set at 10,554.00 MT which is less than the maximum allowable offtake rate (25,000.00 MT). The dual cost of $0.00 represents the savings to be made by increasing the offtake rate by road at the port of Abidjan by one more MT. As the offtake is less than the offtake capacity the savings to be made by increasing the offtake are zero. Hence, the shadow price for the offtake is also zero. In the case of road offtake from Cotonou, the offtake is constrained. In this case, the dual cost ($13.41) shows that an economic return would be derived by increasing the road offtake from that port.

The port summary shows that if investment capital was available for increasing the ports offtake rates, it would be best invested by increasing the road offtake from Cotonou, as greatest economic benefit would be obtained by this investment strategy.

Node Summary: The node summary is similar to the port summary described above. Each time period is reported separately, and only nodes which have demand are reported. Table 3-2 shows a sample node summary.

Table 3-2 summarizes the situation for the first of a two time period problem. The amount of demand met in that time period is shown as well as the cost of delivering the next MT of food-aid to that node (i.e., the shadow price on the demand), and the volume that is required by airlift. The cost of the next MT delivered portrays the relevant accessibility of the node in economic terms. Nodes which are easy to supply will have the least delivery costs; those which are most inaccessible have the greatest cost. In Table 3-2 Bamako is the cheapest to supply while Abeche is the most costly. No airlift is required for any of the examples given; instead, all delivery can take place via surface transportation routes.

Storage Summary: The storage summaries report the volume of food-aid requiring storage at the end of each time period, at the various nodes where storage facilities exist. Table 3-3 shows a sample storage summary.

TABLE 3-2

Sample Node Summary

Node Summary

Model: Fields III Time Period 1 of 2

Node	Demand Met	Cost of Next MT	Airlifts
Abeche	5300.00	$ 217.70	0.00
Agadez	5753.00	$ 146.69	0.00
Ansango	1200.00	$ 121.99	0.00
Bamako	6000.00	$ 105.42	0.00
Birnin	1915.00	$ 106.27	0.00

The storage summaries show the volume of food-aid requiring storage at each node at the end of each time-period. The storage capacity is shown along with the shadow price (i. e., dual cost) on the storage volume. In the first two examples shown (i. e., Abeche, Amtiman), the required volume of storage is equal to the maximum capacity. The dual values show the saving to be made by increasing the volume of storage at those nodes. For example, if the maximum volume that could be stored at Abeche was raised to 201.00 MT per month, a saving of $778.65 could be shown over the planning horizon. In the case of Bobo Dioulasso, the volume stored is less than the maximum feasible storage, hence, there is no economic benefit to be gained by increasing the size of the storage facilities at this node.

TABLE 3-3

Sample Storage Summary

Storage Summary

Model: Fields III Time Period 1 of 2

Node	Volume	Capacity	Dual Cost
Abeche	200.00	200.00	$778.65
Amtiman	200.00	200.00	$780.70
Bobo	157.00	5000.00	$0.00

Arc Summary: The arc summary reports the volume of flow along all arcs which are used in the solution. Capacitized arcs are identified, and dual information on their capacities is also given. Table 3-4 shows such data taken from a sample West African problem.

Arc summary tables consists of each arc in the solution which has a flow along it (twins with flow are also reported), as well as arcs which are explicitly closed (i.e., have a shipping capacity of zero). The origin and destination of each arc, as well as the mode associated with it, is given. The volume of flow, the capacity of the arc and the shadow price associated with the capacity is shown. Where the capacity is set to infinity, the dual cost on capacity is not applicable as the arc will never be constrained. In this example, the rail from Abidjan to Ferke (Ferkeskedougou) is a

TABLE 3-4

Sample Arc Summary

Arc Summary

Model: Fields III Time Period 1 of 2

From	To	Mode	Volume	Capacity	Dual
Abidjan	Ferke.	RD	10554.00	15000.00	$0.00
Abidjan	Ferke.	RL	12500.00	12500.00	$11.44
Agadez	Arlit	RD	3835.00	Inf.	N/A.
Ansango	Gao	RD	14600.00	Inf.	N/A.
Ansango	Meneke.	RD	1320.00	Inf.	N/A.
Banfora	Bobo	RL	15000.00	15000.00	$1.79

constrained arc (i.e., the volume of flow is equal to the maximum allowable shipping capacity). The dual in this case ($11.44), indicates the savings to be made by increasing the arc capacity by one more unit (i.e., one more MT per month).

General Summary: The last summary given in the report writer is a general summary. This table summarizes the demands and offtake over the whole planning horizon. The cost of solution is also given. Table 3-5 is an example of a general summary.

The general summary provides cumulative statistics on the solution. The total cost of solution represents the value of the objective function (i.e., all arc costs plus all airlift costs plus all storage costs incurred). The

TABLE 3-5

Sample General Summary

General Summary
Model: Fields III Time Periods All of 2
Total Cost of Solution........$ 57,705,616.00
Total Demand Met..................276,168.00 MT
Total Volume of Offtake..........246,239.00 MT
Total Volume of Airlifts...........29,929.00 MT
Total Volume of Storage.............2,157.00 MT
Average Length of Haul..............1,272.53 K
Average Delivery Cost..............$ 208.95

total demand met is the number of MT of food-aid delivered to demand nodes in the network. In this example, the total demand met is equal to the volume of offtake and the volume of airlifts. The average length of haul shows the average distance over which each unit of food-aid travels while the average delivery cost shows the average cost of delivering each MT of food-aid to the areas of demand.

3.3 Graphic Depiction

The report writer consists of two parts, the first is the interpretation of the LP solution in tabular form, while the second is a graphical presentation of the network. The graphics driver is written in Microsoft C for use on enhanced graphics computer systems.

The role of the graphics module is to present the solution to the problem in a user-friendly manner. The graphics module reconstructs the solution by using latitudes and longitudes supplied with the node information and reports flows by mode, and the nodes where demand, storage, and airlift occur for each time period. The flows and node characteristics are color coded to allow better visual presentation of the data. The user-interface is menu-driven allowing the user to view any, or all of the network in any given time-period.

CHAPTER 4

WEST AFRICA 1985: A CASE STUDY

The following case study uses data based on the 1984-85 emergency. The network used consists of the major arterial routes which could be taken by the food-aid transports during the relief efforts, and, similarly, the nodes are the major secondary distribution points, transportation hubs, and ports in the region. The multi-period LP problem described in Chapter Two is used to obtain the optimal distribution of food-aid over a two period planning horizon where the first period represents a dry season and the second represents a wet season.

4.1 The Transportation Network

The network lies in the following sub-Saharan countries: Senegal, Mauritania, Mali, Ivory Coast, Togo, Benin, Nigeria, Cameroon, Burkina Faso, Chad, and Niger (see Figure 4-1). The majority of the demand for food-aid lies in the interior countries of Mauritania, Mali, Burkina Faso, Niger, and Chad. The states of Senegal, Ivory Coast, Nigeria, Cameroon, Togo, and Benin are corridor countries as defined earlier.

Seasonal variations in the network mostly affect the low quality roads to be found in the interior of sub-

Saharan Africa. The effects of the rainy season are to make low quality roads impassable. Thus, some of the more remote demand nodes have considerably reduced accessibility in the wet season (Figure 4-1).

<u>Ports:</u> Eight ports are included in the network: Dakar in Senegal; Abidjan in Ivory Coast; Lome and Cotonou in Togo; Lagos, Port Harcourt, and Calabar in Nigeria; and Douala in Cameroon. These were the principal ports used during the last food-related emergency (1984-85). Offtake from the ports are by road and rail only (See Appendix A).

<u>Demand Nodes:</u> Forty-eight of the 77 nodes in the network have a demand for food-aid. The total demand per season is estimated at approximately 138,000.00 MT of food-aid. The demands at each node are assumed to be constant for each time period (see Appendix B). It should be noted that the demands could be modeled as a total for the planning horizon rather than as separate demands in each period.[43] By not dividing the overall planning horizon into separable time periods, it is possible that no food-aid would be delivered to a particular demand node until the end period.

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[43]In this case, the demands for each time period would be set to zero except for the final period when demands would be set to the total aggregate demand for the planning horizon.

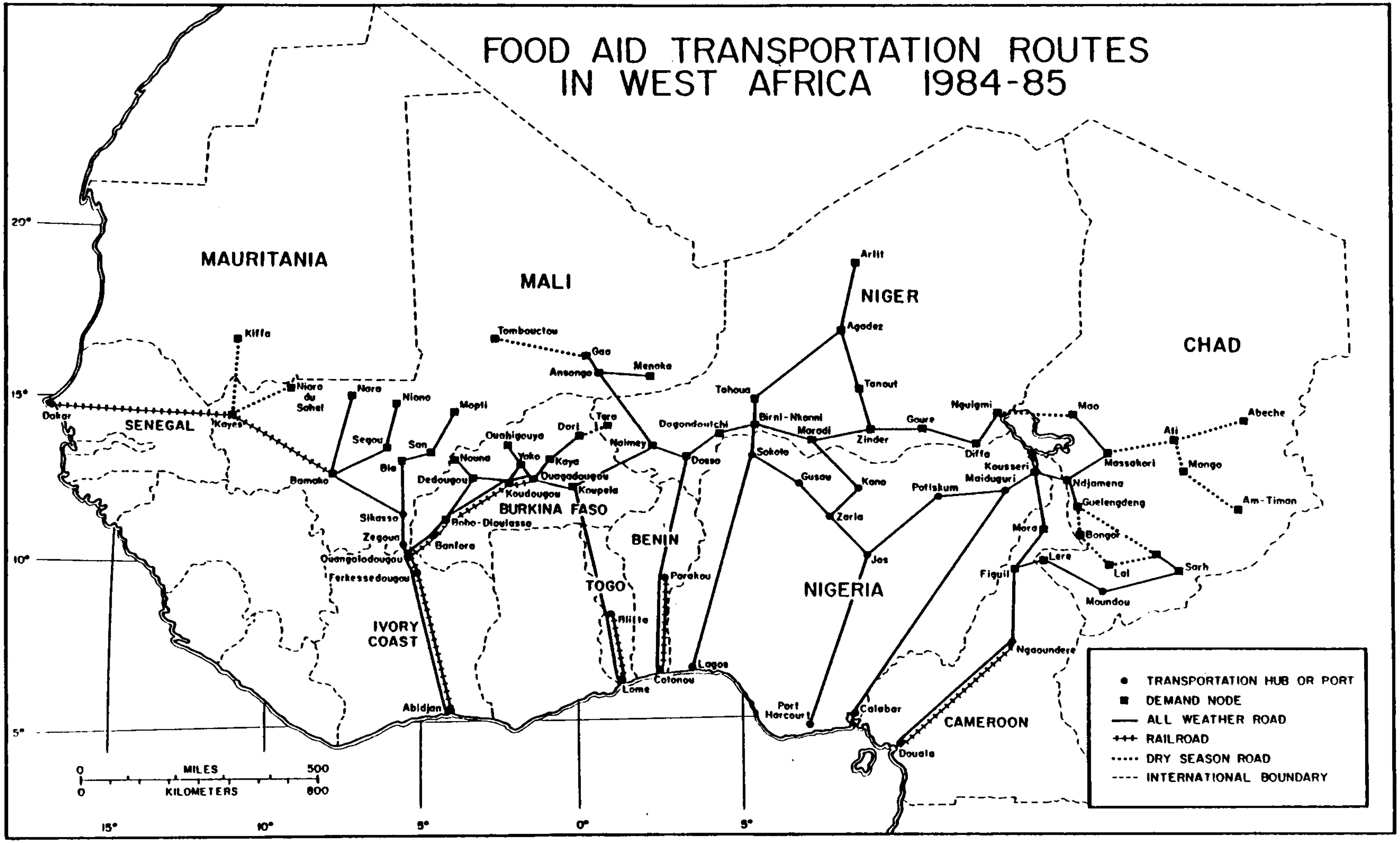

Figure 4-1

Food-Aid Transportation Routes in West Africa 1984-85

<u>Storage Facilities:</u> Data on storage facilities is limited. Food-aid officials in Washington estimate that approximately 200 MT could be stored at secondary distribution centers and up to 5,000 MT of food-aid could be stored at major cities (i.e., capital cities) and transportation hubs. The cost of using these storage facilities is estimated at 12 cents per day per MT ($3.65 per month per MT).[44] Of the 77 nodes in the network, 32 have storage facilities available.

<u>Arc Costs:</u> One hundred arcs are included in the transportation network. Of these arcs, 69 are assumed to be bi-directional and 23 are capacitated in the first time period. In the second period, 37 arcs are capacitated; a result of the effects of the rainy season. Fourteen of these capacitated arcs are shut (i.e., have a shipping capacity of zero). The costs for traversing the arcs are constant for each time period (See Appendix C).[45]

4.2 The Solution

The pre-processor generated an LP tableau of 497

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[44]Data on storage facilities is sketchy because little information about storage facilities is available. Data is currently being collected for use with the FIELDS models in the event of a future emergency.

[45]This is an over assumption as the cost for all forms of transport is likely to increase in the wet season. However, wet period data is as yet unavailable.

variables by 385 constraints. The total cost of solution was found at $57,705,616.00. This included the cost of delivering 29,929.00 MT by airlift and 246,239.00 MT by surface route. The summaries generated by the report writer are given in Appendix A.

4.2.1 <u>Time Period 1</u>

The first time period (the dry season) shows a total offtake over and above that required as a minimum demand in the same time period. 140,241.00 MT of food-aid was delivered to ports and shipped inland while 138,084.00 MT of food-aid were delivered to demand nodes. The remaining 2,157.00 MT were stored at various nodes within the network where accessibility is severely decreased during the wet season (APPENDIX A).

No airlift was required during the first season. The transportation network was sufficiently open to allow full delivery by surface transport.

4.2.2 <u>Time Period 2</u>

The second time period (the wet season) shows the effects of the seasonal variation on the transportation infrastructure. There are 14 roads which become impassable during the rains, resulting in reduced accessibility at Ati, Mao, and Sarh in Chad, and Nioro in Mali. Moreover, Abeche, Am-Timan, Bongor, Gulendgeng, Lai, and Mongo in Chad, Kiffa in Mauritania, Tombouctou in Mali, and Tera in Niger become totally inaccessible by surface transport.

As a result of the reduced accessibility, airlift becomes the only solution to the problem. However, because the food-aid stored during the dry season, the amount of airlift required is minimized. Storage occurred at the following nodes: Abeche, Am-Timan, Bongor, Lai, and Mongo in Chad; Bobo in Burkina Faso; Kiffa in Mauritania; Mopti, Nioro, and Tombouctou in Mali; and Tera in Niger. At those nodes which suffered from total inaccessibility, the amount of airlift required was equal to the amount of demand minus the amount of food-aid stored from the pervious season (32,086.00 - 2,157.00 = 29,929.00). In all such cases, all available storage was used.

The volume of offtake from the ports was reduced as less food-aid was required on the surface transportation network for the second time period. A total of 105,998.00 MT were transported inland from the ports in the second time period, a reduction of 32,243.00 MT over the dry season. The total demand for the second time period was 138,084.00 which was made up of the total offtake for the second time period, plus the amount of storage from the first time period and the amount of airlift in the second time period (105,998.00 + 2,157.00 + 29,929.00 =

138,084.00). No storage occurred during the second period (APPENDIX A).

All the food-aid distributed on the network by both air and surface transportation was used as demand (i.e., total supply equaled total demand over the planning horizon).

4.3 Marginal Analysis

The solution to the LP problem provides a means whereby the food-aid administrators can schedule the delivery and inland transportation of aid. The above example, however, shows that the variation in seasonal characteristics of the network becomes costly.

The total inaccessibility of certain parts of the network means airlift is required. Financial investment in the network could, however, reduce the necessity for airlift. Nodes could be made more accessible by upgrading certain parts of the network to make certain roads are passable in all seasons. An alternative investment strategy would be to invest in storage facilities at the nodes, thus, allowing more shipment of food-aid during the dry season when transportation is cheaper. Either of these investment strategies could reduce the total cost of the solution. Using the FIELDS models, these two investment strategies could be compared.

An analysis of the dual solution via the reduced costs and shadow prices gives the user of the FIELDS system valuable information regarding the best characteristics of the network as targets for potential for future investment.

Port Offtake: The dual values associated with the port offtake rates provide valuable information on the state of the ports in the network. From the port summaries, it can be seen that only three of the port offtake rates were constrained in the first time period. The most expensive constraining offtake rate is that for Dakar by rail. A savings of $36.04 could be realized if this offtake rate could be increased by one more MT. The offtake rates for the second time period show the effects of reduced traffic in the wet season. Less food-aid can be transported along the inland transportation routes, thus, the offtake rates are less. Again, excess capacity exists at most ports. However, in the case of Dakar, the marginal return on the offtake rate by rail has risen to $39.69. This increase shows the effects of reduced accessibility in the road network.

Demands: The shadow prices on the demands in each time period give a good indication of areas where the rainy season reduces the accessibility of certain nodes.

The shadow prices of the demand nodes in the first time period are considerably lower than that for the second period at those nodes where accessibility is reduced. Abeche, Chad, for example, had a shadow price of $217.70 in the first time period. The price for the second time period was $1000.00. This higher shadow price in the second time period shows that the accessibility of Abeche is severely reduced. A single MT increase in demand in the second time period would cost a further $1000.00 to deliver. This high cost reflects the use of airlifts and is equal to the cost of airlifting an extra MT of food-aid.

Storage: The shadow prices on the storage capacity constraints indicate the economic benefit of increasing the size of available storage at each node where storage facilities exist. If the use of the storage facilities falls below the maximum threshold (i.e., storage capacity), then the associated dual value would be zero as no economic benefit would occur by increasing the size of unused storage. Bamako in the first time period is an example here. The total volume stored at Bamako in the first time period is 157 MT out of a maximum capacity of 5000 MT. As the use is below the capacity, the dual value on capacity is zero.

If, however, the total volume of storage at a node is filled in a particular time period, the dual value would indicate the savings to be realized by increasing the capacity by one more MT. Ten nodes in the first time period have the storage facilities used to capacity. The high dual costs associated with the constraints indicate that a large economic benefit could be realized by increasing the size of storage facilities. In this case, the high dual costs associated with storage capacity, combined with the reduced accessibility of these particular nodes in the wet season, and the volumes of required airlift, show that a large decrease in total cost could occur. This decrease in cost could be realized if the storage facilities at these nodes could be increased to accommodate the full demand for the nodes in the wet season, thus reducing the need for airlift.

Arc Flows: Those arcs which suffer from reduced accessibility in the wet season have shadow prices (on the shipping capacity constraints) equal to the savings that could be realized by allowing flow along them. If an arc is constrained, the shadow price will be either zero or a positive value. In the first case, a zero value shows that even though the arc is constrained, a further increase in the shipping capacity would not realize any economic benefit. This would occur in cases where another constraint is limiting the flow along the arc, for instance, in a case where the an arc leaving a port has an offtake rate equal to the shipping capacity of the arc.

In the second case, the shadow price will reflect the importance of the arc in question. For example, the road from Kayes in Senegal to Kiffa in Mauritania is unconstrained in the first time period. It is also the only means of access to the demand associated with Kiffa. In the wet season, the road becomes impassable. The shipping capacity in this case is zero, and the arc is constrained. The shadow price in the dry season was zero (an infinite volume of flow is assumed). In the wet season, however, the shadow price associated with the Kayes-Kiffa road becomes $882.24. This increase reflects the decrease in costs which could be realized by keeping the road open during the wet season. In the case study shown above, of those arcs which become impassable in the wet season, an analysis of the shadow prices could indicate those arcs where greatest investment potential occurs. In this example, the border road from Dori in Burkina Faso to Tera in Niger becomes the arc with the greatest potential for investment.

4.3 Discussion

The problem described and solved above can be regarded as an example of food-aid logistics pre-planning in operation. The above scenario could have been used in one of two cases; either the solution to an emergency situation which already exists, or, alternatively, as a scenario of a situation which could occur. In the first case, the solution would indicate the likely cost of resolving the food-aid emergency. The solution indicates the areas where problems of accessibility are likely to occur in the wet season and the amount and location of airlift and storage requirements. In an emergency situation, when the time frame is important, more attention would be given to the primal solution of the problem rather than the dual.[46] This is because the dual solution gives investment information such as which roads to upgrade or the best location to increase the size of storage facilities.

Some of the dual information is, however, pertinent to emergency conditions. For instance, a slight benefit could be gained by increasing the offtake by rail from Dakar. If the authorities in Dakar were willing to give higher priority to food-aid shipments, this benefit could be realized. Another important aspect of the dual solution under emergency conditions occurs when temporary storage facilities are available. The storage of food-aid

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[46]An "emergency" from the perspective of the food-aid administrators might consist of a time frame of up to six months before a situation becomes critical. The administrators then have up to six months to prepare and plan a relief effort.

under temporary, quickly erected shelters is a distinct possibility in a future emergency. In such a case, the dual solution on storage facilities would indicate the most efficient locations for such shelters.

The total volume of offtake in any time period is greater than the demand and few arcs are constrained in the first time period. Thus, the network is adequate in the dry season but suffers in the wet. To resolve this situation requires investment in storage facilities and/or road upgrading. Both of these strategies are costly and time consuming to effect, and thus, are not pertinent to emergency conditions. In this case the food-aid administrators should make preparations for airlifting approximately 30,000 MT of food-aid in the wet season.

If the problem described above were being run as a likely scenario in the event of a future emergency situation, the dual information becomes more important. The major question is how to reduce the amount of airlift necessary in a wet season. There is sufficient offtake capacity in both the wet and dry seasons to allow the total demand to be satisfied by surface transportation. The accessibility question must, however, be examined. The arc summary in time period 2 (APPENDIX A-7) shows those arcs which are constrained and the marginal returns to be gained by increasing their capacities. The most important arcs in terms of marginal returns are those which are closed during the wet season and act as sole links for certain demand nodes. The Kayes-Kiffa road from Mali to Mauritania, for instance, is one such road. The marginal cost of this road in the wet season ($882.24) shows that a considerable saving could be made by making this road passable in the wet season. Other examples are the road from Mass to Ati in Chad ($854.49), Gao to Tombouctou in Mali ($826.22), and Gulendgeng to Bongor ($881.09) also in Chad. The administrators can, therefore, identify important links and invest in the most cost-efficient manner.

The marginal returns on the storage capacities are similarly informative. The dual values on the storage capacity show the benefits to be gained by increasing the size of the storage facilities. At Kiffa, for example, a $882.24 saving could be made by investing in a larger storage facility.

Having thus identified areas where investment in the storage and transportation infrastructure of the network could be realized, it is up to the administrators to ascertain the potential of such investment in the long term. For instance, would it be better to upgrade the road or invest in storage facilities at, say, Timbouctou? Maybe the best solution is to do both; that is, upgrade the road and invest in larger storage facilities. The actual answer lies in the resources available to the administrators. If the problem of the road from Gao to Timbouctou is in the quality of the road or in the availability of transports capable of traversing it, then in the latter case, an investment in adequate trucks would probably be more advantageous in the long run. However, if the road gets washed out during floods and bridges are required to keep the road open, then considerably more investment is required. In this case, maybe increasing the size of storage facilities is the best answer, thus, the required amount of food-aid for the wet season could be pre-positioned during the dry season (i.e., during times of maximum accessibility), and stored until the wet season.

To resolve such questions, the administrators would make the required adjustments to the data base (i.e., increase the size of the storage facilities at Timbouctou, or alternatively, increase the shipping capacity during the wet season,) and re-solve the problem. By a process of resetting the values associated with certain nodes and arcs, and re-solving the problem, the best investment scenarios could be derived without any real investment taking place. Thus, administrators, through a series of scenarios, can identify areas where problems are likely to occur during emergency food-aid distribution, and derive the best feasible methods for resolving such problems while staying within the bounds of their available resources.

SUMMARY AND CONCLUSIONS

This study examines the logistical problems surrounding the delivery of food-aid to areas of need in sub-Saharan Africa and used the information to produce a DSS capable of helping in the distribution of food-aid in emergency situations. A multi-period LP model was developed to help facilitate the administrators' ability to solve large complicated logistical problems of the type described. This LP model was incorporated into a set of decision support tools to complete an integrated DSS capable of large scale relief planning.

The development of such DSS systems has several advantages over currently practiced methods of food-aid scheduling:

(1) The LP model is robust; thus, the DSS can be used on any networks bearing constraints common to the West African situation. In essence, any network which has the same basic characteristics could be used and it may be applied at any geographic scale.

(2) Once the initial data bases are constructed, new scenarios can be developed and solved in a relatively short time. Thus, a variety of scenarios could be quickly appraised allowing timely analysis of the major problems facing an emergency situation.

(3) A means whereby many donor organizations can

cooperate and so maximize the potential of their relief efforts is necessary. The DSS as described would allow a central management team to coordinate the delivery of food-aid to ports and inland nodes with maximum efficiency. A time-table of delivery schedules can easily be developed and act as benchmarks by which donors and transportation firms might operate. In the event that unforseen contingencies arise (such as the loss of some transportation links), new time-tables could be quickly developed.

(4) The marginal economic information which is available through an analysis of the dual solution provide important investment information. Thus, during times when no emergency exists, investment scenarios could be developed and tested.

The DSS described above does, however, require some strong assumptions. These assumptions are pertinent to the use of LP models for solving transportation problems in general and are not specific to this model.

First, the costs are assumed to be linear. For instance, food-aid is distributed by bulk carrier; either trucks of relatively large capacity, rail cars, barges or air transport. It may be more realistic, in this case, to assume transportation costs are a function of the size and volume of the transport vehicles being used. Similarly, the costs of storing food-aid at the nodes is a function of the storage facility size and cost of guarding the food. Thus, it might be as expensive to store a single MT in a warehouse as it would be to fill the entire warehouse with food-aid. In this case, the storage question becomes a "mixed-integer" problem rather than a straight LP.

Secondly, disbenefits of under-utilizing facilities is not accounted for. For instance, a better solution than one obtained given the present models assumption might be derived by reassigning flow from a partly used rail transport and using the roads instead.

The output of the DSS should be regarded as a feasible solution and not necessarily the only answer to the problem. The objective function derived from the LP model reflects the cost for solving the model as given at a particular point in time. The solution is only as good as the data which serve as input to the model and should be regarded as such. In essence, the transportation network is complex and dynamic by nature; the supply and demand equilibria are, therefore, likely to shift. In such a case, the administrators should be able to adapt to the changing situations by using the solutions generated by the DSS as a basis for decisionmaking and not necessarily as a decision in itself.

The future success of large scale famine relief operations such as those witnessed in 1984-85 depends, to a large part, on the ability of administrators to maximize the use of the resources available to them. This involves the careful collection and assimilation of a variety of data, development of logistical plans, and the ascertainment of the necessary means to carry out any proposed plan. The DSS as described above is one step towards that goal.

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APPENDIXES

APPENDIX A

Report Summaries

APPENDIX A-1

P O R T   S U M M A R Y

Time Period: 1 of 2 Model: West Africa Thesis 1

PORT	Offtake (MT/Month)	Mode	Offtake Capacity (MT/Month)	Savings On Capacity
ABIDJAN	10554.00	RD	25000.00	$ 0.00
ABIDJAN	12500.00	RL	15000.00	$ 0.00
CALABAR	10413.00	RD	20000.00	$ 0.00
COTONOU	12000.00	RD	12000.00	$ 13.41
COTONOU	12500.00	RL	20000.00	$ 0.00
DAKAR	15000.00	RL	15000.00	$ 36.04
DOUALA	0.00	RD	3000.00	$ 0.00
DOUALA	30000.00	RL	30000.00	$ 9.39
LAGOS	0.00	RD	0.00	$ 35.43
LOME	15000.00	RD	15000.00	$ 0.00
LOME	10000.00	RL	12000.00	$ 0.00
PTHARC	12274.00	RD	20000.00	$ 0.00

APPENDIX A-2

N O D E   S U M M A R Y

Time Period: 1 of 2 Model: West Africa Thesis 1

Node	Demand Met (MT/Month)	Cost of next MT delivered	Airlifts (MT/Month)
ABECHE	5300.00	$ 217.70	0.00
AGADEZ	5753.00	$ 146.69	0.00
ANSANGO	1200.00	$ 121.99	0.00
AMTIMAN	3055.00	$ 215.65	0.00
ARLIT	3835.00	$ 165.39	0.00
ATI	3763.00	$ 154.90	0.00
BAMAKO	6000.00	$ 105.42	0.00
BIRNIN	1915.00	$ 106.27	0.00
BLA	2370.00	$ 86.56	0.00
BOBO	2593.00	$ 57.84	0.00
BONGOR	3710.00	$ 128.30	0.00
DEDOUGOU	1216.00	$ 78.95	0.00
DIFFA	2301.00	$ 163.63	0.00
DOGON	1918.00	$ 95.11	0.00
DORI	1388.00	$ 108.95	0.00
DOSSO	1910.00	$ 84.50	0.00
GAO	7200.00	$ 129.31	0.00
GOURE	2301.00	$ 147.14	0.00
KAYA	1355.00	$ 89.06	0.00
KAYES	7200.00	$ 79.83	0.00
KIFFA	1182.00	$ 114.11	0.00
KOUPELA	1815.00	$ 67.27	0.00
KOUDOUGOU	1321.00	$ 71.67	0.00
LAI	3180.00	$ 150.50	0.00
MAO	3710.00	$ 129.28	0.00
MARADI	1905.00	$ 116.11	0.00
MENAKE	1320.00	$ 138.15	0.00
MONGO	3180.00	$ 178.00	0.00
MOPTI	1176.00	$ 94.26	0.00
MOUNDOU	3710.00	$ 114.84	0.00
NARA	1194.00	$ 151.40	0.00
NDJAM	4505.00	$ 100.24	0.00
NGUIGMI	1899.00	$ 176.71	0.00
NIAMEY	4794.00	$ 95.19	0.00
NIONO	1215.00	$ 106.76	0.00
NIORO	1182.00	$ 110.45	0.00
NOUNA	1251.00	$ 85.90	0.00
OUAGA	3421.00	$ 104.10	0.00
OUIHA	1286.00	$ 90.22	0.00
SAN	2400.00	$ 78.76	0.00
SARH	5300.00	$ 150.22	0.00

SEGOU	1260.00	$	93.94	0.00
TAHOUA	5753.00	$	115.66	0.00
TANOUT	1937.00	$	153.88	0.00
TERA	959.00	$	119.93	0.00
TOMBOUC	7200.00	$	181.04	0.00
YAKO	1815.00	$	81.31	0.00
ZINDER	1931.00	$	134.36	0.00

APPENDIX A-3

STORAGE SUMMARY

Time Period: 1 of 2 Model: West Africa Thesis 1

Node	Storage Required (MT/Month)	Storage Capacity (MT/Month)	Savings on Capacity
ABECHE	200.00	200.00	$ 778.65
AMTIMAN	200.00	200.00	$ 780.70
BAMAKO	157.00	5000.00	$ 0.00
BONGOR	200.00	200.00	$ 868.05
KIFFA	200.00	200.00	$ 882.24
LAI	200.00	200.00	$ 845.85
MONGO	200.00	200.00	$ 818.35
MOPTI	200.00	200.00	$ 0.00
NIORO	200.00	200.00	$ 47.67
TERA	200.00	200.00	$ 876.42
TOMBOUC	200.00	200.00	$ 815.31

APPENDIX A-4

A R C S U M M A R Y

Time Period: 1 of 2 Model: West Africa Thesis 1

From	To	Mode	Arc Flow (MT/Month)	Arc Capacity (MT/Month)	Savings on Capacity
ABIDJAN	FERKE	RD	10554.00	15000.00	$ 0.00
ABIDJAN	FERKE	RL	12500.00	12500.00	$ 11.44
AGADEZ	ARLIT	RD	3835.00	Infinity	N/A
ANSANGO	GAO	RD	14600.00	Infinity	N/A
ANSANGO	MENAKE	RD	1320.00	Infinity	N/A
ATI	ABECHE	RD	5500.00	Infinity	N/A
ATI	MONGO	RD	6635.00	Infinity	N/A
BAMAKO	NARA	RD	1194.00	Infinity	N/A
BANFORA	BOBO	RD	8039.00	Infinity	N/A
BANFORA	BOBO	RL	12500.00	12500.00	$ 1.79
BIRNIN	TAHOUA	RD	15341.00	Infinity	N/A
SAN	BLA	RD	4845.00	Infinity	N/A
BLA	SEGOU	RD	2475.00	Infinity	N/A
BLITTA	KOUPELA	RD	25000.00	Infinity	N/A
BOBO	SAN	RD	8421.00	Infinity	N/A
BOBO	KOUDOUGOU	RL	7058.00	12500.00	$ 0.00
BOBO	DEDOUGOU	RD	2467.00	Infinity	N/A
BONGOR	LAI	RD	3380.00	Infinity	N/A
CALABAR	MAIDUGURI	RD	10413.00	18750.00	$ 0.00
COTONOU	PARAKOU	RD	12000.00	25000.00	$ 0.00
COTONOU	PARAKOU	RL	12500.00	12500.00	$ 22.61
DAKAR	KAYES	RL	15000.00	20000.00	$ 0.00
DEDOUGOU	NOUNA	RD	1251.00	Infinity	N/A
DIFFA	NGUIGMI	RD	1899.00	Infinity	N/A
DOGON	BIRNIN	RD	17256.00	Infinity	N/A
DORI	TERA	RD	1159.00	Infinity	N/A
DOSSO	DOGON	RD	19174.00	Infinity	N/A
DOSSO	NIAMEY	RD	3416.00	Infinity	N/A
DOUALA	NGOUND	RL	30000.00	37500.00	$ 0.00
FERKE	OUANGOLO	RD	10554.00	Infinity	N/A
FERKE	OUANGOLO	RL	12500.00	12500.00	$ 0.93
FIGUIL	LERE	RD	9010.00	Infinity	N/A
FIGUIL	MORA	RD	20990.00	Infinity	N/A
GAO	TOMBOUC	RD	7400.00	Infinity	N/A
GOURE	DIFFA	RD	4200.00	Infinity	N/A
GUELENGD	BONGOR	RD	7290.00	Infinity	N/A
JOS	ZARIA	RD	12274.00	Infinity	N/A
KANO	MARADI	RD	12274.00	Infinity	N/A
KAYA	DORI	RD	12274.00	Infinity	N/A
KAYES	BAMAKO	RL	5036.00	20000.00	$ 0.00
KAYES	KIFFA	RD	1382.00	Infinity	N/A

KAYES	NIORO	RD	1382.00	Infinity		N/A
KOUDOUGOU	OUAGA	RL	2636.00	12500.00	$	0.00
KOUDOUGOU	YAKO	RD	3101.00	Infinity		N/A
KOUPELA	NIAMEY	RD	18498.00	Infinity		N/A
KOUPELA	OUAGA	RD	4687.00	Infinity		N/A
KOUSSERI	NDJAM	RD	31403.00	Infinity		N/A
LERE	MOUNDOU	RD	9010.00	Infinity		N/A
LOME	BLITTA	RD	15000.00	15000.00	$	7.26
LOME	BLITTA	RL	10000.00	10000.00	$	12.83
MAIDUGURI	KOUSSERI	RD	10413.00	Infinity		N/A
MARADI	ZINDER	RD	10369.00	Infinity		N/A
MASS	ATI	RD	15898.00	Infinity		N/A
MASS	MAO	RD	3710.00	Infinity		N/A
MONGO	AMTIMAN	RD	3255.00	Infinity		N/A
MORA	KOUSSERI	RD	20990.00	Infinity		N/A
MOUNDOU	SARH	RD	5300.00	Infinity		N/A
NDJAM	MASS	RD	19608.00	Infinity		N/A
NDJAM	GUELENGD	RD	7290.00	Infinity		N/A
NGOUND	FIGUIL	RD	30000.00	Infinity		N/A
NIAMEY	ANSANGO	RD	17120.00	Infinity		N/A
OUAGA	KAYA	RD	3902.00	Infinity		N/A
OUANGOLO	BANFORA	RD	8396.00	Infinity		N/A
OUANGOLO	ZEGOUA	RD	2158.00	15000.00	$	0.00
OUANGOLO	BANFORA	RL	12500.00	12500.00	$	1.85
PARAKOU	DOSSO	RD	24500.00	Infinity		N/A
PTHARC	JOS	RD	12274.00	18750.00	$	0.00
SAN	MOPTI	RD	1176.00	Infinity		N/A
SEGOU	NIONO	RD	1215.00	Infinity		N/A
SIKASSO	BAMAKO	RD	2158.00	Infinity		N/A
TAHOUA	AGADEZ	RD	9588.00	Infinity		N/A
YAKO	OUIHA	RD	1286.00	Infinity		N/A
ZARIA	KANO	RD	12274.00	Infinity		N/A
ZEGOUA	SIKASSO	RD	2158.00	Infinity		N/A
ZINDER	GOURE	RD	6501.00	Infinity		N/A
ZINDER	TANOUT	RD	1937.00	Infinity		N/A

APPENDIX A-5

PORT SUMMARY

Time Period: 2 of 2 Model: West Africa Thesis 1

PORT	Offtake (MT/Month)	Mode	Offtake Capacity (MT/Month)	Savings On Capacity
ABIDJAN	1000.00	RD	25000.00	$ 0.00
ABIDJAN	12500.00	RL	15000.00	$ 0.00
CALABAR	0.00	RD	20000.00	$ 0.00
COTONOU	12000.00	RD	12000.00	$ 6.15
COTONOU	12500.00	RL	20000.00	$ 0.00
DAKAR	15000.00	RL	15000.00	$ 39.69
DOUALA	0.00	RD	3000.00	$ 0.00
DOUALA	17225.00	RL	30000.00	$ 0.00
LAGOS	0.00	RD	0.00	$ 28.17
LOME	13499.00	RD	15000.00	$ 0.00
LOME	10000.00	RL	12000.00	$ 0.00
PTHARC	12274.00	RD	20000.00	$ 0.00

APPENDIX A-6

N O D E S U M M A R Y

Time Period: 2 of 2 Model: West Africa Thesis 1

Node	Demand Met (MT/Month)	Cost of next MT delivered	Airlifts (MT/Month)
ABECHE	5300.00	$ 1000.00	5100.00
AGADEZ	5753.00	$ 139.43	0.00
ANSANGO	1200.00	$ 114.73	0.00
AMTIMAN	3055.00	$ 1000.00	2855.00
ARLIT	3835.00	$ 158.31	0.00
ATI	3763.00	$ 1000.00	3763.00
BAMAKO	6000.00	$ 109.07	0.00
BIRNIN	1915.00	$ 99.01	0.00
BLA	2370.00	$ 90.21	0.00
BOBO	2593.00	$ 61.49	0.00
BONGOR	3710.00	$ 1000.00	3510.00
DEDOUGOU	1216.00	$ 82.60	0.00
DIFFA	2301.00	$ 163.61	0.00
DOGON	1918.00	$ 87.85	0.00
DORI	1388.00	$ 101.69	0.00
DOSSO	1910.00	$ 77.30	0.00
GAO	7200.00	$ 122.05	0.00
GOURE	2301.00	$ 147.14	0.00
KAYA	1355.00	$ 81.80	0.00
KAYES	7200.00	$ 83.48	0.00
KIFFA	1182.00	$ 1000.00	982.00
KOUPELA	1815.00	$ 59.29	0.00
KOUDOUGOU	1321.00	$ 75.27	0.00
LAI	3180.00	$ 1000.00	2980.00
MAO	3710.00	$ 119.89	0.00
MARADI	1905.00	$ 116.11	0.00
MENAKE	1320.00	$ 130.89	0.00
MONGO	3180.00	$ 1000.00	2980.00
MOPTI	1176.00	$ 97.91	0.00
MOUNDOU	3710.00	$ 105.45	0.00
NARA	1194.00	$ 155.05	0.00
NDJAM	4505.00	$ 90.85	0.00
NGUIGMI	1899.00	$ 176.71	0.00
NIAMEY	4794.00	$ 87.93	0.00
NIONO	1215.00	$ 110.41	0.00
NIORO	1182.00	$ 161.77	0.00
NOUNA	1251.00	$ 89.55	0.00
OUAGA	3421.00	$ 69.84	0.00
OUIHA	1286.00	$ 88.27	0.00
SAN	2400.00	$ 82.51	0.00
SARH	5300.00	$ 170.83	0.00

SEGOU	1260.00	$	96.99	0.00
TAHOUA	5753.00	$	108.40	0.00
TANOUT	1937.00	$	153.88	0.00
TERA	959.00	$	1000.00	759.00
TOMBOUC	7200.00	$	1000.00	7000.00
YAKO	1815.00	$	79.36	0.00
ZINDER	1931.00	$	134.36	0.00

APPENDIX A-7

A R C S U M M A R Y

Time Period: 2 of 2 Model: West Africa Thesis 1

From	To	Mode	Arc Flow (MT/Month)	Arc Capacity (MT/Month)	Savings on Capacity
ABIDJAN	FERKE	RD	1000.00	15000.00	$ 0.00
ABIDJAN	FERKE	RL	12500.00	12500.00	$ 11.44
AGADEZ	ARLIT	RD	3835.00	Infinity	N/A
ANSANGO	GAO	RD	7200.00	Infinity	N/A
ANSANGO	MENAKE	RD	1320.00	Infinity	N/A
ATI	ABECHE	RD	0.00	0.00	$ 0.00
ATI	MONGO	RD	0.00	0.00	$ 0.00
BAMAKO	NARA	RD	1194.00	Infinity	N/A
BAMAKO	NIORO	RD	982.00	Infinity	N/A
BANFORA	BOBO	RD	981.00	Infinity	N/A
BANFORA	BOBO	RL	12500.00	12500.00	$ 1.79
BIRNIN	TAHOUA	RD	15341.00	Infinity	N/A
SAN	BLA	RD	4845.00	Infinity	N/A
BLA	SEGOU	RD	2475.00	Infinity	N/A
BLITTA	KOUPELA	RD	23499.00	Infinity	N/A
BOBO	SAN	RD	8421.00	Infinity	N/A
BOBO	DEDOUGOU	RD	2467.00	Infinity	N/A
BONGOR	LAI	RD	0.00	0.00	$ 0.00
COTONOU	PARAKOU	RD	12000.00	25000.00	$ 0.00
COTONOU	PARAKOU	RL	12500.00	12500.00	$ 15.35
DAKAR	KAYES	RL	15000.00	20000.00	$ 0.00
DEDOUGOU	NOUNA	RD	1251.00	Infinity	N/A
DIFFA	NGUIGMI	RD	1899.00	Infinity	N/A
DOGON	BIRNIN	RD	17256.00	Infinity	N/A
DOSSO	DOGON	RD	19174.00	Infinity	N/A
DOSSO	NIAMEY	RD	3416.00	Infinity	N/A
DOUALA	NGOUND	RL	17225.00	37500.00	$ 0.00
FERKE	OUANGOLO	RD	1000.00	Infinity	N/A
FERKE	OUANGOLO	RL	12500.00	12500.00	$ 4.58
FIGUIL	LERE	RD	9010.00	Infinity	N/A
FIGUIL	MORA	RD	8215.00	Infinity	N/A
GOURE	DIFFA	RD	4200.00	Infinity	N/A
GAO	TOMBOUC	RD	0.00	0.00	$ 826.22
GUELENGD	BONGOR	RD	0.00	0.00	$ 881.09
GUELENGD	GAYAM	RD	0.00	0.00	$ 0.00
JOS	ZARIA	RD	12274.00	Infinity	N/A
KANO	MARADI	RD	12274.00	Infinity	N/A
KAYA	DORI	RD	1388.00	Infinity	N/A
KAYES	BAMAKO	RL	7800.00	20000.00	$ 0.00
KAYES	KIFFA	RD	0.00	0.00	$ 882.24
KAYES	NIORO	RD	0.00	0.00	$ 47.67

OUAGA	KOUDOUGOU	RL	1321.00	12500.00	$	0.00
KOUPELA	NIAMEY	RD	11098.00	Infinity		N/A
KOUPELA	OUAGA	RD	10586.00	Infinity		N/A
KOUSSERI	NDJAM	RD	8215.00	Infinity		N/A
LAI	GAYAM	RD	0.00	0.00	$	0.00
LERE	MOUNDOU	RD	9010.00	Infinity		N/A
LOME	BLITTA	RD	13499.00	15000.00	$	0.00
LOME	BLITTA	RL	10000.00	10000.00	$	5.57
MARADI	ZINDER	RD	10369.00	Infinity		N/A
MASS	ATI	RD	0.00	0.00	$	854.49
MASS	MAO	RD	3710.00	Infinity		N/A
MONGO	AMTIMAN	RD	0.00	0.00	$	0.00
MORA	KOUSSERI	RD	8215.00	Infinity		N/A
MOUNDOU	SARH	RD	5300.00	Infinity		N/A
NDJAM	MASS	RD	3710.00	Infinity		N/A
NGUIMI	MAO	RD	0.00	0.00	$	0.00
NGOUND	FIGUIL	RD	17225.00	Infinity		N/A
NIAMEY	ANSANGO	RD	9720.00	Infinity		N/A
OUAGA	KAYA	RD	2743.00	Infinity		N/A
OUAGA	YAKO	RD	3101.00	Infinity		N/A
OUANGOLO	BANFORA	RD	624.00	Infinity		N/A
OUANGOLO	ZEGOUA	RD	376.00	15000.00	$	0.00
OUANGOLO	BANFORA	RL	12500.00	12500.00	$	1.85
PARAKOU	DOSSO	RD	24500.00	Infinity		N/A
PTHARC	JOS	RD	12274.00	18750.00	$	0.00
SAN	MOPTI	RD	1176.00	Infinity		N/A
SEGOU	NIONO	RD	1215.00	Infinity		N/A
SIKASSO	BAMAKO	RD	376.00	Infinity		N/A
TAHOUA	AGADEZ	RD	9588.00	Infinity		N/A
YAKO	OUIHA	RD	1286.00	Infinity		N/A
ZARIA	KANO	RD	12274.00	Infinity		N/A
ZEGOUA	SIKASSO	RD	376.00	Infinity		N/A
ZINDER	GOURE	RD	6501.00	Infinity		N/A
ZINDER	TANOUT	RD	1937.00	Infinity		N/A

APPENDIX A-8

G E N E R A L   S U M M A R Y

Time Periods: ALL of 2 Model: West Africa Thesis 1

Total Cost of Solution.......$	57705616.00	
Total Demand Met..............	276168.00	MT
Total Volume of Offtake.......	246239.00	MT
Total Volume of Airlifts......	29929.00	MT
Total Volume of Storage.......	2157.00	MT
Average Length of Haul........	1272.53	K
Average Delivery Cost........$	212.43	MT

APPENDIX B

Ports Data File

Port	Road	Rail	Water
ABIDJAN	25000.00	15000.00	-1.00
CALABAR	20000.00	-1.00	-1.00
COTONOU	12000.00	20000.00	-1.00
DAKAR	-1.00	15000.00	-1.00
DOUALA	3000.00	30000.00	-1.00
LAGOS	0.00	-1.00	-1.00
LOME	15000.00	12000.00	-1.00
PTHARC	20000.00	-1.00	-1.00
ENDDATA			
ABIDJAN	25000.00	15000.00	-1.00
CALABAR	20000.00	-1.00	-1.00
COTONOU	12000.00	20000.00	-1.00
DAKAR	-1.00	15000.00	-1.00
DOUALA	3000.00	30000.00	-1.00
LAGOS	0.00	-1.00	-1.00
LOME	15000.00	12000.00	-1.00
PTHARC	20000.00	-1.00	-1.00

APPENDIX B

Nodes Data File

Node	Demand	Storage Cost	Storage Capacity	Air Cost	Graphic Codes	
ABECHE	5300.00	3.65	200.00	1000.00	1.88	7.42
ABIDJAN	0.00	3.65	-1.00	1000.00	3.51	2.54
AGADEZ	5753.00	3.65	200.00	1000.00	1.25	4.95
ANSANGO	1200.00	3.65	5000.00	1000.00	1.48	3.50
AMTIMAN	3055.00	3.65	200.00	1000.00	2.35	7.35
ARLIT	3835.00	3.65	200.00	1000.00	0.92	4.85
ATI	3763.00	3.65	-1.00	1000.00	2.00	6.94
BAMAKO	6000.00	3.65	5000.00	1000.00	2.01	1.83
BANFORA	0.00	3.65	5000.00	1000.00	2.45	2.43
BIRNIN	1915.00	3.65	5000.00	1000.00	1.87	4.41
BLA	2370.00	3.65	-1.00	1000.00	1.97	2.27
BLITTA	0.00	3.65	-1.00	1000.00	2.95	3.53
BOBO	2593.00	3.65	5000.00	1000.00	2.33	2.53
BONGOR	3710.00	3.65	200.00	1000.00	2.45	6.45
CALABAR	0.00	3.65	-1.00	1000.00	3.63	4.97
COTONOU	0.00	3.65	-1.00	1000.00	3.34	3.81
DAKAR	0.00	3.65	-1.00	1000.00	1.49	0.04
DEDOUGOU	1216.00	3.65	-1.00	1000.00	2.09	2.70
DIFFA	2301.00	3.65	200.00	1000.00	1.99	5.83
DOGON	1918.00	3.65	-1.00	1000.00	1.90	4.16
DORI	1388.00	3.65	-1.00	1000.00	1.80	3.39
DOSSO	1910.00	3.65	-1.00	1000.00	2.03	3.99
DOUALA	0.00	3.65	-1.00	1000.00	3.83	5.24
FERKE	0.00	3.65	-1.00	1000.00	2.66	2.34
FIGUIL	0.00	3.65	-1.00	1000.00	2.80	6.14
GAO	7200.00	3.65	200.00	1000.00	1.35	3.41
GAYAM	0.00	3.65	-1.00	1000.00	2.48	7.25
GOURE	2301.00	3.65	-1.00	1000.00	1.85	5.38
GUELENGD	0.00	3.65	-1.00	1000.00	2.50	6.50
GUSAU	0.00	3.65	-1.00	1000.00	2.20	4.67
JOS	0.00	3.65	-1.00	1000.00	2.65	5.09
KANO	0.00	3.65	-1.00	1000.00	2.23	5.04
KAYA	1355.00	3.65	-1.00	1000.00	1.99	3.17
KAYES	7200.00	3.65	-1.00	1000.00	1.62	1.20
KIFFA	1182.00	3.65	200.00	1000.00	1.17	1.25
KOUPELA	1815.00	3.65	5000.00	1000.00	2.18	3.30
KOUSSERI	0.00	3.65	-1.00	1000.00	2.23	6.29
KOUDOUGOU	1321.00	3.65	-1.00	1000.00	2.15	2.92
LAGOS	0.00	3.65	-1.00	1000.00	3.32	4.01
LAI	3180.00	3.65	200.00	1000.00	2.65	6.90
LERE	0.00	3.65	-1.00	1000.00	2.70	6.50
LOME	0.00	3.65	-1.00	1000.00	3.40	3.56
MAIDUGURI	0.00	3.65	-1.00	1000.00	2.27	5.94
MAO	3710.00	3.65	200.00	1000.00	1.83	6.35
MARADI	1905.00	3.65	-1.00	1000.00	1.94	4.76
MASS	0.00	3.65	-1.00	1000.00	1.15	6.37
MENAKE	1320.00	3.65	200.00	1000.00	1.45	3.86
MONGO	3180.00	3.65	200.00	1000.00	2.30	6.90
MOPTI	1176.00	3.65	200.00	1000.00	1.68	2.59

MORA	0.00	3.65	-1.00	1000.00	2.44	6.12
MOUNDOU	3710.00	3.65	200.00	1000.00	2.79	6.90
NARA	1194.00	3.65	200.00	1000.00	1.52	2.01
NDJAM	4505.00	3.65	5000.00	1000.00	2.22	6.30
NGOUND	0.00	3.65	-1.00	1000.00	3.17	6.01
NGUIGMI	1899.00	3.65	5000.00	1000.00	1.80	5.93
NIAMEY	4794.00	3.65	5000.00	1000.00	1.92	3.79
NIONO	1215.00	3.65	200.00	1000.00	1.72	2.24
NIORO	1182.00	3.65	200.00	1000.00	1.48	1.56
NOUNA	1251.00	3.65	200.00	1000.00	2.04	2.63
OUAGA	3421.00	3.65	-1.00	1000.00	2.13	3.07
OUANGOLO	0.00	3.65	-1.00	1000.00	2.59	2.35
OUIHA	1286.00	3.65	200.00	1000.00	1.88	2.92
PARAKOU	0.00	3.65	-1.00	1000.00	2.76	3.86
POTISKUM	0.00	3.65	-1.00	1000.00	2.30	5.52
PTHARC	0.00	3.65	-1.00	1000.00	3.67	4.71
SAN	2400.00	3.65	200.00	1000.00	1.92	2.44
SARH	5300.00	3.65	200.00	1000.00	2.70	7.40
SEGOU	1260.00	3.65	-1.00	1000.00	1.88	2.18
SIKASSO	0.00	3.65	-1.00	1000.00	2.32	2.26
SOKOTO	0.00	3.65	-1.00	1000.00	2.02	4.40
TAHOUA	5753.00	3.65	-1.00	1000.00	1.65	4.42
TANOUT	1937.00	3.65	-1.00	1000.00	1.65	5.11
TERA	959.00	3.65	200.00	1000.00	1.82	3.53
TOMBOUC	7200.00	3.65	200.00	1000.00	1.22	2.85
YAKO	1815.00	3.65	-1.00	1000.00	2.00	2.94
ZEGOUA	0.00	3.65	-1.00	1000.00	2.48	2.26
ZARIA	0.00	3.65	-1.00	1000.00	2.42	4.87
ZINDER	1931.00	3.65	-1.00	1000.00	1.88	5.13
ENDDATA						
ABECHE	5300.00	3.65	200.00	1000.00	1.88	7.42
ABIDJAN	0.00	3.65	-1.00	1000.00	3.51	2.54
AGADEZ	5753.00	3.65	200.00	1000.00	1.25	4.95
ANSANGO	1200.00	3.65	5000.00	1000.00	1.48	3.50
AMTIMAN	3055.00	3.65	200.00	1000.00	2.35	7.35
ARLIT	3835.00	3.65	200.00	1000.00	0.92	4.85
ATI	3763.00	3.65	-1.00	1000.00	2.00	6.94
BAMAKO	6000.00	3.65	5000.00	1000.00	2.01	1.83
BANFORA	0.00	3.65	5000.00	1000.00	2.45	2.43
BIRNIN	1915.00	3.65	5000.00	1000.00	1.87	4.41
BLA	2370.00	3.65	-1.00	1000.00	1.97	2.27
BLITTA	0.00	3.65	-1.00	1000.00	2.95	3.53
BOBO	2593.00	3.65	5000.00	1000.00	2.33	2.53
BONGOR	3710.00	3.65	200.00	1000.00	2.45	6.45
CALABAR	0.00	3.65	-1.00	1000.00	3.63	4.97
COTONOU	0.00	3.65	-1.00	1000.00	3.34	3.81
DAKAR	0.00	3.65	-1.00	1000.00	1.49	0.04
DEDOUGOU	1216.00	3.65	-1.00	1000.00	2.09	2.70
DIFFA	2301.00	3.65	200.00	1000.00	1.99	5.83
DOGON	1918.00	3.65	-1.00	1000.00	1.90	4.16
DORI	1388.00	3.65	-1.00	1000.00	1.80	3.39
DOSSO	1910.00	3.65	-1.00	1000.00	2.03	3.99

DOUALA	0.00	3.65	-1.00	1000.00	3.83	5.24
FERKE	0.00	3.65	-1.00	1000.00	2.66	2.34
FIGUIL	0.00	3.65	-1.00	1000.00	2.80	6.14
GAO	7200.00	3.65	200.00	1000.00	1.35	3.41
GAYAM	0.00	3.65	-1.00	1000.00	2.48	7.25
GOURE	2301.00	3.65	-1.00	1000.00	1.85	5.38
GUELENGD	0.00	3.65	-1.00	1000.00	2.50	6.50
GUSAU	0.00	3.65	-1.00	1000.00	2.20	4.67
JOS	0.00	3.65	-1.00	1000.00	2.65	5.09
KANO	0.00	3.65	-1.00	1000.00	2.23	5.04
KAYA	1355.00	3.65	-1.00	1000.00	1.99	3.17
KAYES	7200.00	3.65	-1.00	1000.00	1.62	1.20
KIFFA	1182.00	3.65	200.00	1000.00	1.17	1.25
KOUPELA	1815.00	3.65	5000.00	1000.00	2.18	3.30
KOUSSERI	0.00	3.65	-1.00	1000.00	2.23	6.29
KOUDOUGOU	1321.00	3.65	-1.00	1000.00	2.15	2.92
LAGOS	0.00	3.65	-1.00	1000.00	3.32	4.01
LAI	3180.00	3.65	200.00	1000.00	2.65	6.90
LERE	0.00	3.65	-1.00	1000.00	2.70	6.50
LOME	0.00	3.65	-1.00	1000.00	3.40	3.56
MAIDUGURI	0.00	3.65	-1.00	1000.00	2.27	5.94
MAO	3710.00	3.65	200.00	1000.00	1.83	6.35
MARADI	1905.00	3.65	-1.00	1000.00	1.94	4.76
MASS	0.00	3.65	-1.00	1000.00	1.15	6.37
MENAKE	1320.00	3.65	200.00	1000.00	1.45	3.86
MONGO	3180.00	3.65	200.00	1000.00	2.30	6.90
MOPTI	1176.00	3.65	200.00	1000.00	1.68	2.59
MORA	0.00	3.65	-1.00	1000.00	2.44	6.12
MOUNDOU	3710.00	3.65	200.00	1000.00	2.79	6.90
NARA	1194.00	3.65	200.00	1000.00	1.52	2.01
NDJAM	4505.00	3.65	5000.00	1000.00	2.22	6.30
NGOUND	0.00	3.65	-1.00	1000.00	3.17	6.01
NGUIGMI	1899.00	3.65	5000.00	1000.00	1.80	5.93
NIAMEY	4794.00	3.65	5000.00	1000.00	1.92	3.79
NIONO	1215.00	3.65	200.00	1000.00	1.72	2.24
NIORO	1182.00	3.65	200.00	1000.00	1.48	1.56
NOUNA	1251.00	3.65	200.00	1000.00	2.04	2.63
OUAGA	3421.00	3.65	-1.00	1000.00	2.13	3.07
OUANGOLO	0.00	3.65	-1.00	1000.00	2.59	2.35
OUIHA	1286.00	3.65	200.00	1000.00	1.88	2.92
PARAKOU	0.00	3.65	-1.00	1000.00	2.76	3.86
POTISKUM	0.00	3.65	-1.00	1000.00	2.30	5.52
PTHARC	0.00	3.65	-1.00	1000.00	3.67	4.71
SAN	2400.00	3.65	200.00	1000.00	1.92	2.44
SARH	5300.00	3.65	200.00	1000.00	2.70	7.40
SEGOU	1260.00	3.65	-1.00	1000.00	1.88	2.18
SIKASSO	0.00	3.65	-1.00	1000.00	2.32	2.26
SOKOTO	0.00	3.65	-1.00	1000.00	2.02	4.40
TAHOUA	5753.00	3.65	-1.00	1000.00	1.65	4.42
TANOUT	1937.00	3.65	-1.00	1000.00	1.65	5.11
TERA	959.00	3.65	200.00	1000.00	1.82	3.53
TOMBOUC	7200.00	3.65	200.00	1000.00	1.22	2.85

YAKO	1815.00	3.65	-1.00	1000.00	2.00	2.94
ZEGOUA	0.00	3.65	-1.00	1000.00	2.48	2.26
ZARIA	0.00	3.65	-1.00	1000.00	2.42	4.87
ZINDER	1931.00	3.65	-1.00	1000.00	1.88	5.13

APPENDIX C

Arcs Data File

Origin	Dest.	Mode	Distance	Cost	Capacity	Flag
ABIDJAN	FERKE	RD	534.0	.077	15000.0	1
ABIDJAN	FERKE	RL	530.0	.056	12500.0	1
AGADEZ	ARLIT	RD	243.0	.077	-1.0	1
ANSANGO	GAO	RD	95.0	.077	-1.0	0
ANSANGO	MENAKE	RD	210.0	.077	-1.0	0
ATI	ABECHE	RD	314.0	.200	-1.0	1
ATI	MONGO	RD	154.0	.150	-1.0	1
BAMAKO	SEGOU	RD	235.0	.077	-1.0	0
BAMAKO	SEGOU	WT	228.0	.050	0.0	0
BAMAKO	NARA	RD	377.0	.122	-1.0	1
BAMAKO	NIORO	RD	432.0	.122	-1.0	0
BANFORA	BOBO	RD	85.0	.077	-1.0	0
BANFORA	BOBO	RL	85.0	.056	12500.0	0
BIRNIN	MARADI	RD	250.0	.077	-1.0	0
BIRNIN	TAHOUA	RD	122.0	.077	-1.0	0
BLA	SAN	RD	100.0	.077	-1.0	0
BLA	SEGOU	RD	88.0	.077	-1.0	0
BLITTA	KOUPELA	RD	505.0	.077	-1.0	1
BOBO	KOUDOUGOU	RD	291.0	.077	-1.0	0
BOBO	SAN	RD	273.0	.077	-1.0	0
BOBO	KOUDOUGOU	RL	247.0	.056	12500.0	0
BOBO	DEDOUGOU	RD	173.0	.122	-1.0	0
BONGOR	LAI	RD	148.0	.150	-1.0	0
CALABAR	MAIDUGURI	RD	1067.0	.077	18750.0	1
COTONOU	PARAKOU	RD	438.0	.077	25000.0	1
COTONOU	PARAKOU	RL	438.0	.056	12500.0	1
DAKAR	KAYES	RL	782.0	.056	20000.0	1
DEDOUGOU	NOUNA	RD	57.0	.122	-1.0	0
DIFFA	NGUIGMI	RD	170.0	.077	-1.0	0
DOGON	BIRNIN	RD	145.0	.077	-1.0	0
DORI	TERA	RD	90.0	.122	-1.0	1
DOSSO	DOGON	RD	137.0	.077	-1.0	0
DOSSO	NIAMEY	RD	138.0	.077	-1.0	0
DOUALA	NGOUND	RD	1151.0	.077	1000.0	1
DOUALA	NGOUND	RL	762.0	.056	37500.0	1
FERKE	OUANGOLO	RD	44.0	.077	-1.0	1
FERKE	OUANGOLO	RL	44.0	.056	12500.0	1
FIGUIL	LERE	RD	38.0	.122	-1.0	1
FIGUIL	MORA	RD	119.0	.077	-1.0	0
GAO	TOMBOUC	WT	424.0	.050	0.0	0
GAO	TOMBOUC	RD	424.0	.122	-1.0	0
GAYAM	SARH	RD	50.0	.150	-1.0	0
GOURE	DIFFA	RD	214.0	.077	-1.0	0
GUELENGD	BONGOR	RD	83.0	.150	-1.0	0
GUELENGD	GAYAM	RD	356.0	.150	-1.0	0
GUSAU	SOKOTO	RD	220.0	.077	-1.0	0
JOS	POTISKUM	RD	361.0	.077	-1.0	0
JOS	ZARIA	RD	238.0	.077	-1.0	0
KANO	MARADI	RD	266.0	.077	-1.0	0
KAYA	DORI	RD	163.0	.122	-1.0	1

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KAYES       BAMAKO     RL     457.0   .056   20000.0 0
KAYES       KIFFA      RD     281.0   .122      -1.0 1
KAYES       NIORO      RD     251.0   .122      -1.0 0
KOUDOUGOU   OUAGA      RD      86.0   .077      -1.0 0
KOUDOUGOU   OUAGA      RL      97.0   .056   12500.0 0
KOUDOUGOU   DEDOUGOU   RD     128.0   .122      -1.0 0
KOUDOUGOU   YAKO       RD      79.0   .122      -1.0 0
KOUPELA     NIAMEY     RD     372.0   .077      -1.0 0
KOUPELA     OUAGA      RD     137.0   .077      -1.0 0
KOUSSERI    NDJAM      RD      35.0   .077      -1.0 0
LAGOS       SOKOTO     RD    1013.0   .077      -1.0 1
LAI         GAYAM      RD     179.0   .150      -1.0 1
LERE        MOUNDOU    RD     305.0   .122      -1.0 1
LOME        BLITTA     RD     265.0   .077   15000.0 1
LOME        BLITTA     RL     265.0   .056   10000.0 1
MAIDUGURI   KOUSSERI   RD     200.0   .077      -1.0 0
MARADI      ZINDER     RD     237.0   .077      -1.0 0
MASS        ATI        RD     402.0   .122      -1.0 1
MASS        MAO        RD     192.0   .122      -1.0 0
MONGO       AMTIMAN    RD     251.0   .150      -1.0 0
MOPTI       GAO        RD     588.0   .077   10000.0 0
MOPTI       TOMBOUC    WT     400.0   .050       0.0 0
MORA        KOUSSERI   RD     200.0   .077      -1.0 1
MOUNDOU     SARH       RD     290.0   .122      -1.0 0
NDJAM       MASS       RD      46.0   .122      -1.0 0
NDJAM       GUELENGD   RD     156.0   .100      -1.0 0
NGOUND      FIGUIL     RD     272.0   .077      -1.0 1
NGUIGMI     MAO        RD     327.0   .200      -1.0 0
NIAMEY      ANSANGO    RD     348.0   .077      -1.0 0
OUAGA       KAYA       RD      98.0   .122      -1.0 1
OUAGA       YAKO       RD      78.0   .122      -1.0 0
OUANGOLO    BANFORA    RD      88.0   .077      -1.0 0
OUANGOLO    ZEGOUA     RD     126.0   .077   15000.0 0
OUANGOLO    BANFORA    RL      88.0   .056   12500.0 0
PARAKOU     DOSSO      RD     486.0   .077      -1.0 1
POTISKUM    MAIDUGURI  RD     235.0   .077      -1.0 0
PTHARC      JOS        RD     832.0   .077   18750.0 1
SAN         MOPTI      RD     200.0   .077      -1.0 0
SEGOU       MOPTI      WT     303.0   .050       0.0 0
SEGOU       NIONO      RD     110.0   .122      -1.0 1
SIKASSO     BAMAKO     RD     374.0   .077      -1.0 0
SIKASSO     BLA        RD     203.0   .077      -1.0 0
SOKOTO      BIRNIN     RD      93.0   .077      -1.0 0
TAHOUA      AGADEZ     RD     403.0   .077      -1.0 0
TANOUT      AGADEZ     RD     287.0   .122      -1.0 0
YAKO        OUIHA      RD      73.0   .122      -1.0 1
ZARIA       GUSAU      RD     184.0   .077      -1.0 0
ZARIA       KANO       RD     172.0   .077      -1.0 0
ZEGOUA      SIKASSO    RD     291.0   .077      -1.0 0
ZINDER      GOURE      RD     166.0   .077      -1.0 0
ZINDER      TANOUT     RD     160.0   .122      -1.0 0
ENDDATA
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ABIDJAN	FERKE	RD	534.0	.077	15000.0	1
ABIDJAN	FERKE	RL	530.0	.056	12500.0	1
AGADEZ	ARLIT	RD	243.0	.077	-1.0	1
ANSANGO	GAO	RD	95.0	.077	-1.0	0
ANSANGO	MENAKE	RD	210.0	.077	-1.0	0
ATI	ABECHE	RD	314.0	.200	0.0	1
ATI	MONGO	RD	154.0	.150	0.0	1
BAMAKO	SEGOU	RD	235.0	.077	-1.0	0
BAMAKO	SEGOU	WT	228.0	.050	0.0	0
BAMAKO	NARA	RD	377.0	.122	-1.0	1
BAMAKO	NIORO	RD	432.0	.122	-1.0	0
BANFORA	BOBO	RD	85.0	.077	-1.0	0
BANFORA	BOBO	RL	85.0	.056	12500.0	0
BIRNIN	MARADI	RD	250.0	.077	-1.0	0
BIRNIN	TAHOUA	RD	122.0	.077	-1.0	0
BLA	SAN	RD	100.0	.077	-1.0	0
BLA	SEGOU	RD	88.0	.077	-1.0	0
BLITTA	KOUPELA	RD	505.0	.077	-1.0	1
BOBO	KOUDOUGOU	RD	291.0	.077	-1.0	0
BOBO	SAN	RD	273.0	.077	-1.0	0
BOBO	KOUDOUGOU	RL	247.0	.056	12500.0	0
BOBO	DEDOUGOU	RD	173.0	.122	-1.0	0
BONGOR	LAI	RD	148.0	.150	0.0	0
CALABAR	MAIDUGURI	RD	1067.0	.077	18750.0	1
COTONOU	PARAKOU	RD	438.0	.077	25000.0	1
COTONOU	PARAKOU	RL	438.0	.056	12500.0	1
DAKAR	KAYES	RL	782.0	.056	20000.0	1
DEDOUGOU	NOUNA	RD	57.0	.122	-1.0	0
DIFFA	NGUIGMI	RD	170.0	.077	-1.0	0
DOGON	BIRNIN	RD	145.0	.077	-1.0	0
DORI	TERA	RD	90.0	.122	0.0	1
DOSSO	DOGON	RD	137.0	.077	-1.0	0
DOSSO	NIAMEY	RD	138.0	.077	-1.0	0
DOUALA	NGOUND	RD	1151.0	.077	1000.0	1
DOUALA	NGOUND	RL	762.0	.056	37500.0	1
FERKE	OUANGOLO	RD	44.0	.077	1000.0	1
FERKE	OUANGOLO	RL	44.0	.056	12500.0	1
FIGUIL	LERE	RD	38.0	.122	-1.0	1
FIGUIL	MORA	RD	119.0	.077	-1.0	1
GAO	TOMBOUC	WT	424.0	.050	0.0	0
GAO	TOMBOUC	RD	424.0	.122	0.0	0
GAYAM	SARH	RD	50.0	.150	-1.0	0
GOURE	DIFFA	RD	214.0	.077	-1.0	0
GUELENGD	BONGOR	RD	83.0	.150	0.0	0
GUELENGD	GAYAM	RD	356.0	.150	0.0	0
GUSAU	SOKOTO	RD	220.0	.077	-1.0	0
JOS	POTISKUM	RD	361.0	.077	-1.0	0
JOS	ZARIA	RD	238.0	.077	-1.0	0
KANO	MARADI	RD	266.0	.077	-1.0	0
KAYA	DORI	RD	163.0	.122	-1.0	1
KAYES	BAMAKO	RL	457.0	.056	20000.0	0
KAYES	KIFFA	RD	281.0	.122	0.0	1

KAYES	NIORO	RD	251.0	.122	0.0	0
KOUDOUGOU	OUAGA	RD	86.0	.077	-1.0	0
KOUDOUGOU	OUAGA	RL	97.0	.056	12500.0	0
KOUDOUGOU	DEDOUGOU	RD	128.0	.122	-1.0	0
KOUDOUGOU	YAKO	RD	79.0	.122	-1.0	0
KOUPELA	NIAMEY	RD	372.0	.077	-1.0	0
KOUPELA	OUAGA	RD	137.0	.077	-1.0	0
KOUSSERI	NDJAM	RD	35.0	.077	-1.0	0
LAGOS	SOKOTO	RD	1013.0	.077	-1.0	1
LAI	GAYAM	RD	179.0	.150	0.0	1
LERE	MOUNDOU	RD	305.0	.122	-1.0	1
LOME	BLITTA	RD	265.0	.077	15000.0	1
LOME	BLITTA	RL	265.0	.056	10000.0	1
MAIDUGURI	KOUSSERI	RD	200.0	.077	-1.0	0
MARADI	ZINDER	RD	237.0	.077	-1.0	0
MASS	ATI	RD	402.0	.122	0.0	1
MASS	MAO	RD	192.0	.122	-1.0	0
MONGO	AMTIMAN	RD	251.0	.150	0.0	0
MOPTI	GAO	RD	588.0	.077	10000.0	0
MOPTI	TOMBOUC	WT	400.0	.050	0.0	0
MORA	KOUSSERI	RD	200.0	.077	-1.0	1
MOUNDOU	SARH	RD	290.0	.122	-1.0	0
NDJAM	MASS	RD	46.0	.122	-1.0	0
NDJAM	GUELENGD	RD	156.0	.100	-1.0	0
NGOUND	FIGUIL	RD	272.0	.077	-1.0	1
NGUIGMI	MAO	RD	327.0	.200	0.0	0
NIAMEY	ANSANGO	RD	348.0	.077	-1.0	0
OUAGA	KAYA	RD	98.0	.122	-1.0	1
OUAGA	YAKO	RD	78.0	.122	-1.0	0
OUANGOLO	BANFORA	RD	88.0	.077	-1.0	0
OUANGOLO	ZEGOUA	RD	126.0	.077	15000.0	0
OUANGOLO	BANFORA	RL	88.0	.056	12500.0	0
PARAKOU	DOSSO	RD	486.0	.077	-1.0	1
POTISKUM	MAIDUGURI	RD	235.0	.077	-1.0	0
PTHARC	JOS	RD	832.0	.077	18750.0	1
SAN	MOPTI	RD	200.0	.077	-1.0	0
SEGOU	MOPTI	WT	303.0	.050	0.0	0
SEGOU	NIONO	RD	110.0	.122	-1.0	1
SIKASSO	BAMAKO	RD	374.0	.077	-1.0	0
SIKASSO	BLA	RD	203.0	.077	-1.0	0
SOKOTO	BIRNIN	RD	93.0	.077	-1.0	0
TAHOUA	AGADEZ	RD	403.0	.077	-1.0	0
TANOUT	AGADEZ	RD	287.0	.122	-1.0	0
YAKO	OUIHA	RD	73.0	.122	-1.0	1
ZARIA	GUSAU	RD	184.0	.077	-1.0	0
ZARIA	KANO	RD	172.0	.077	-1.0	0
ZEGOUA	SIKASSO	RD	291.0	.077	-1.0	0
ZINDER	GOURE	RD	166.0	.077	-1.0	0
ZINDER	TANOUT	RD	160.0	.122	-1.0	0

APPENDIX D

Countries, Names, and Abbreviations

Node	Name	Country
Abeche	Abeche	Chad
Abidjan	Abidjan	Ivory Coast
Agadez	Agadez	Niger
Ansango	Ansango	Mali
Amtiman	Am-Timan	Chad
Arlit	Arlit	Niger
Ati	Ati	Chad
Bamako	Bamako	Mali
Banfora	Banfora	Burkina Faso
Birnin	Birni-Nkonni	Niger
Bla	Bla	Mali
Blitta	Blitta	Togo
Bobo	Bobo-Dioulasso	Burkina Faso
Bongor	Bongor	Chad
Calabar	Calabar	Nigeria
Cotonou	Cotonou	Benin
Dakar	Dakar	Senegal
Dedougou	Dedougou	Burkina Faso
Diffa	Diffa	Niger
Dogon	Dogondoutchi	Niger
Dori	Dori	Burkina Faso
Dosso	Dosso	Niger
Douala	Douala	Cameroon
Ferke	Ferkesskedougou	Ivory Coast
Figuil	Figuil	Cameroon
Gao	Gao	Mali
Gayam	Gayam	Chad
Goure	Goure	Niger
Guelengd	Guelegdeng	Chad
Gusau	Gusau	Nigeria
Jos	Jos	Nigeria
Kano	Kano	Nigeria
Kaya	Kaya	Burkina Faso
Kayes	Kayes	Mali
Kiffa	Kiffa	Mauritania
Koupela	Koupela	Burkina Faso
Kousseri	Kouuseri	Cameroon
Koudougou	Koudougou	Burkina Faso
Lagos	Lagos	Nigeria
Lai	Lai	Chad
Lere	Lere	Chad
Lome	Lome	Togo
Maiguguri	Maiduguri	Nigeria
Mao	Mao	Chad
Maradi	Maradi	Niger
Mass	Masakori	Chad
Menake	Menake	Mali
Mongo	Mongo	Chad
Mopti	Mopti	Mali
Mora	Mora	Cameroon

Moundou	Moundou	Chad
Nara	Nara	Mali
Ndjam	Ndjamena	Chad
Ngound	Ngaoundere	Cameroon
Nguigmi	Nguigmi	Niger
Niamey	Niamey	Mali
Niono	Niono	Mali
Nioro	Nioro Du Sahel	Mali
Nouna	Nouna	Burkina Faso
Ouaga	Ouagadougou	Burkina Faso
Ouangolo	Ouangolodougou	Ivory Coast
Ouhia	Ouhiagouya	Burkina Faso
Parakou	Parakou	Benin
Potiskum	Potiskum	Nigeria
Ptharc	Port Harcourt	Nigeria
San	San	Mali
Sarh	Sarh	Chad
Segou	Segou	Mali
Sikasso	Sikasso	Mali
Sokoto	Sokoto	Nigeria
Tahoua	Tahoua	Niger
Tanout	Tanout	Niger
Tera	Tera	Niger
Tombouc	Tombouctou	Mali
Yako	Yako	Burkina Faso
Zegoua	Zegoua	Mali
Zaria	Zaria	Nigeria
Zinder	Zinder	Niger

VITA

Julian Ray was born in England on November 12, 1962. After attending primary and secondary schools near Warrington, England, he entered the University of Reading, England, and in June 1984 received a Bachelors of Art (Hons.) degree in Human Geography. After working in the Greater London Council (GLC) Planning Department, he accepted a teaching assistantship at the University of Tennessee, Knoxville, in 1985. He received a Master's of Science degree in Geography in August 1987.

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