AN APPROACH TO THE DESIGN OF MANAGEMENT INFORMATION SYSTEMS WITH APPLICATIONS TO FAMINE RELIEF

By

Allan Gerard Knapp

A DISSERTATION

submitted to

Michigan State University

in partial fulfillment of the requirements

for the degree of

DOCTOR OF PHILOSOPHY

Department of Electrical Engineering

and Systems Science

1980

ABSTRACT

AN APPROACH TO THE DESIGN OF MANAGEMENT INFORMATION SYSTEMS WITH APPLICATIONS TO FAMINE RELIEF

By

Allan Gerard Knapp

Management Information System (MIS) design often fails to account for the effect that varying qualities of information and associated in-information costs have on the overall system performance. The focus of this dissertation is to develop an approach for ascertaining optimal information quality levels for given budget constraints in large-scale systems. The methodology is applied to the problems encountered by a country experiencing a food shortage.

The approach consists of three main components: a computer simulation, a cost function, and an optimization procedure. The computer simulation models the background system in which the information system is imbedded; in this case, the demographic, consumption, and production characteristics of the famine-stricken area. A government decision-making component is also modeled to facilitate examination of policy structure. Overall system performance variables, such as reduction of fatalities and maintenance of high nutritional level, are defined to monitor the effects of changing policies or information quality.

An information sampling component is added to the basic simulation model to enable the model's "true" variable values to be disturbed with specific measurement error statistics. Sampling frequency, sampling

error, and processing delays are applied to model variables, thereby simulating surveillance sampling results received by system managers. The variables being measured in the famine context include nutritional level, consumption, and food storage level and location. The quality of information received by system managers is varied, using the sampling component, and corresponding results on overall system performance studied.

The optimization stage can thus specify the "best" information quality mix, in terms of expected outcomes. To tie the information quality to actual surveillance, processing and transmission design, a cost function is constructed. The design detail is restricted to this cost function development so that relief system simulation can be applied at a macro level. Since increased costs are generally associated with improved information quality, the optimization is performed at several budget constraint levels. This provides comparisons of cost effectiveness of individual information quality parameters.

The sampling component and the information quality concept are effective tools for validation of the simulation model and policy structure. Better information levels should lead to better overall system performance. If not, then faulty model or policy structure or the presence of unexpected natural occurrences would be suspected.

The approach provides an evaluation tool for determining useful real-world variables to monitor, desirable information quality levels and comparative performance of separate information quality parameters. It will also enable review of expected overall system outcomes in situations where the level of crisis, policy structure and information quality are all subject to change.

Several general principles for relief efforts emerge from the study: long-term versus short-term fatality reduction goals must be accounted for in distribution policies, the prevailing relationship between rates of consumption and storage patterns should be ascertained, and the level of the crisis must be estimated accurately for effective relief performance.

The approach draws on techniques and concepts from many fields of study, including information filters and predictors, feedback control, optimal statistical sampling, simulation modeling, experimental design, statistical measurement and optimization algorithms. Portions of the methodology can be applied gainfully, particularly the computer simulation as an education tool and on-line decision aid. Modeling and solution techniques are discussed which have general applicability to Management Information Systems. The dissertation concludes with major findings, advantages and disadvantages of the approach and a discussion of further research areas.

DEDICATION

To my wife, Diane

ACKNOWLEDGEMENTS

I first wish to thank Dr. Tom Manetsch for his wise counsel, guidance, and suggestions in my program and research. Without his timely comments, many unfruitful tangents would have been explored. I also express appreciation to the members of my committee for their teaching and cooperation.

The research for this dissertation was funded in part through a research fellowship sponsored by the Midwest University Consortium for International Activities.

My wife Diane has been a consistent source of strength and patience. Her typing and editing skills are only a small part of what makes her invaluable to me. I also want to thank my parents and Diane's parents for their unfailing encouragement and support. And this dissertation could not have been completed without the consistent prayers of our many friends.

Finally, I thank Barbara Reeves and her band of typists for the marathon project this tome has become.

TABLE OF CONTENTS

Page

Page

LIST OF TABLES

LIST OF FIGURES

Page

PART I

COMPUTER MODEL AND COST FUNCTION DEVELOPMENT

Introduction

Famine is a real threat in many parts of the world today. Chronic malnutrition is widespread, leaving populations weak and susceptible to disease. A severe food shortage for even one season in such areas would lead to many deaths due to starvation.

Relief efforts are handicapped when adequate knowledge of needs is not available. Each component of the relief system depends on communication of information. These components include transportation units, field offices, and surveilance teams, as well as planners and decision makers. A Management Information System (MIS) is one way to provide the overall data communication needed. This dissertation is a proposed method for addressing the MIS design problem.

Three major segments constitute the core of the approach. Part I defines the problem and approach, and it contains development of two major segments. First, a computer simulation of a country's experiencing a critical food shortage is described along with an information system component that ties together surveillance data and information quality and their effect on relief system performance. Information filters, policy design, and model structure are all described in relation to system management. The second major segment is a cost function that describes the resource commitments needed for various levels of information quality.

In Part II, the third major segment ties the first two segments together by presenting an optimization problem. The goal is to maximize performance of the overall relief system within a given information system budget. Chapters 8 and 9 explore optimization alternatives and likely approach outputs.

Part III consists of Chapter 10, providing results and conclusions. Observations are given about the approach, the use of a computer simulation, further research, and implications for famine relief systems.

CHAPTER I

THE PROBLEM AND THE APPROACH

Famine poses a serious threat to many nations in the years ahead. In the last decade, food shortages have been caused by war, drought, natural disasters, and crop failure (46). Conflicts in Biafra and Bangladesh have resulted in destruction of food and disruption of normal distribution lines. The Sahelian drought has damaged many countries as the desert advances. Earthquakes, cyclones, and floods have caused food and water shortages in such diverse countries as Peru, India, and Iran. Successive crop failures led to a near catastrophe in the Bihar state of India during the late 1960s (58, Chapter 2).

Unfortunately, the probability of famine's striking has not been adequately reduced, even with the great strides made in food production capability. The problems of overpopulation, inadequate or nonexistent food distribution systems, economic inequality, greed, and corruption combine to create a well-established global system with food shortages a likely output. There is evidence that the earth is entering a period unfavorable to food production, adding a negative environmental input to the system (37). It will take a systematic and cooperative effort to prevent catastrophic famines.

A food shortage has a devastating effect on individuals and on the stricken society. Weight loss and body wasting, apathy, decreased work output and self-centeredness are all common individual symptome. The generally weakened condition of the population leaves it highly susceptible to epidemics. As food stores dwindle, rumors spread quickly, leading to large-scale migrations and hoarding. Crime, civil disturbances, and panic mount.

Planning to meet or offset the consequences of a food shortage can encounter numerous obstacles. Political sensitivities sometimes cause a nation to withhold needed aid. It is also difficult for many countries to acknowledge the existence of famine within its boarders for fear of the unfavorable impression it gives (49). There is little reliable data from past famines. At least three factors have been noted for the scarcity of detailed recordkeeping. An adequate reporting policy has rarely been designed and used. Workers have consistently had a "do" mentality, laboring diligently to aid victims but not taking time to record activities and results. The third factor is the fear that the extent of the disaster may reflect poorly on one's personal efforts, causing silence.

Designs for famine relief sometimes come under the broader heading of disaster relief, which includes short-term encounters such as flood, fire, and earthquake. The special difficulties presented by famine include its longer duration, its often widespread area, and its gradual overtaking of a weakened population. The dramatic intrusion of an earthquake or flood demands immediate and clearly substantial action. The requirements of famine relief are also substantial, but are not as early seen. However, the generally slower development of a food shortage allows prediction and time for planning to minimize the disaster's results. The need for preparation was recognized long ago in the earliest Indian Famine Codes:

> Proceed from the beginning on a comprehensive plan and publish it. Admist the manifold details of a Code, there lies a danger that the broad principles of famine relief may escape the notice of those who have to administer it. It is only on a knowledge of principles that the various incidents of famine administration settle into their proper places, and it is obviously of importance that all controlling officers should understand the principles and bearings of what they have to do (53, p. 12).

The main problem to solve in a food shortage is the distribution of food to those who need it. Many systems must interact fluidly. Planning decisions are needed on the goals of relief operations. Information must be acquired concerning the relative welfare of the population. Food transportation and storage logistics need to be examined. Field level programs of training, education, communication, and resource acquisition support systems are necessary. The problem is not simple, especially when the nations most prone to famine are underdeveloped and unorganized.

The goals for a relief effort will vary by country and by crisis. Normally, the main priority is minimization of the death total (46). Other desirable results from the country's viewpoint could be to keep social disruption low and minimize foreign dependence. Humanitarian beliefs dictate that high nutritional levels, prevention of human performance impairment, and equitable food distribution are necessary goals. The major constraints preventing achievement of established objectives are limited money, personnel, equipment, and time. A shortage of any one of these items can jeopardize an entire relief operation.

Information System Structure

The focus of this dissertation is on the information system needed for famine relief. The importance of information is easily realized by observing that any course of action will be based on available data. Knoweldge of the situation is necessary. The many links between the information system and the transportation, field programs, system managers, donors, and affected population subsystems will be examined here. But the thrust is to provide a systematic means of designing and implementing an efficient, accurate information system that leads to positive results. Such a structure is often labeled a Management Information System (MIS).

Figure 1.1 depicts the general structure of an information system for famine relief. The blocks represent the major groups involved in the relief process. The linkages are information flows, including planning, training, communications, and evaluations. The expected scenario relating a real world food shortage to the structure of Figure 1.1 would be as follows:

> Planners start with the goals and objectives of the famine relief system. They then provide the Teachers, Trainers, and System Managers with the necessary system design, and work is done to prepare for disaster. As a good shortage strikes, the Affected People are observed by Data Collection teams. The surveillance results are tabulated by Data Processing and transmitted to the System Managers. Decisions, based on planned policy and current observations, then flow to Government Programs, Relief Agencies, Field Offices, and the Transport System. Concurrently, Evaluations are made of relief activities, and the Media and Donors respond to the crisis. The cycle is closed as the Field Offices and Media provide the Affected People with needed food and reports on the extent of the shortage.

Several of the component groups and linkages deserve further explanation. The planners are responsible for the overall relief system, including the information system as one component. This dissertation is aimed at planners as an aid in the design and evaluation of data collection, processing, and transmission alternatives. The complex

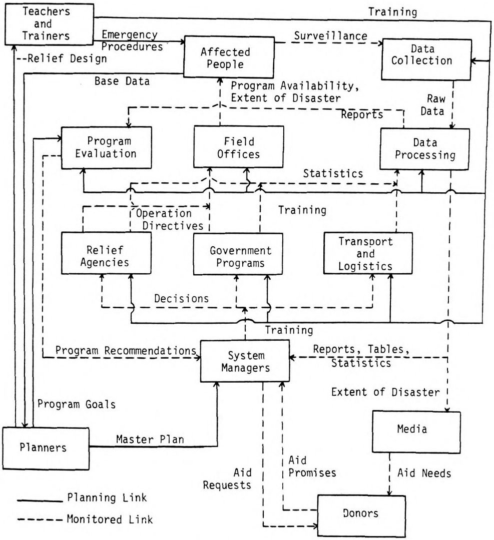


Figure 1.1. Information System for Famine Relief Showing Major Functional Groups and Information Linkages.

interrelationships among the many components allow a study of the information system to shed light on other subsystems. Thus, the approach discussed here also provides indications of policy, management, and training requirements.

One planning element that ties directly to the information system is the need for on-going surveillance. The advantages of simultaneous consideration of long-term continuous and short-term crisis surveillance are numerous. Crop conditions, weather reports, food reserves, retail prices, and anthropometric measures can all serve as warning signals of an approaching crisis. Extant information on population size and distribution, communication lines, and cultural and religious conditions will aid planners in efficient design of emergency operations. A trust and acceptance of survey procedures may develop as the surveys become more commonplace. Cost efficiency can be obtained as equipment and personnel needs are evaluated. And possibly the greatest advantage is that disaster planning will occur well in advance.

Advanced planning will provide relief system managers with a basic policy structure to guide decision-making. Knowledge of overall relief goals is a valuable aid in specific allocation and distribution judgments. This leads to the difference noted in Figure 1.1 between preplanned and on-going information linkages. Planning can provide a policy structure, training, and direction for emergency procedures and evaluation. Once the crisis occurs, system management involves responses based on current available data. Training and the master plan are used to aid flexible, day-to-day decisions. Note that planners and managers may be the same individuals, as there are substantial overlaps in the distinguishable positions.

The decision linkages pictured in Figure 1.1 will depend on the management structure of the affected area. One can envision a group effort with representatives of the transport, field programs, and information systems serving in a guidance role. The literature suggests that one dynamic leader with broad powers has generally had positive results (45).

A missing link in many past relief efforts has been the evaluation of the systems. The evaluation component in Figure 1.1 is needed to improve efficiency in system components, both during a crisis and in future planning. The information and material linkages between components should be singled out for frequent evaluation, to insure smooth transfers of responsibility.

Two valuable assets outside the government system are relief agencies and the international communications media. Interantional groups, such as the Red Cross, CARE, United Nations organizations, and the World Council of Churches, have a great deal of experience and are able to draw on resources not available to the country itself. By presenting an accurate picture of the stricken nation's needs, the international press can help avoid senseless donations. The literature abounds with such incredible examples as winter coats sent to the equator and building materials to starving countries.

The actual "relief" work occurs at the field office level in Figure 1.1. This is the system component where the most real-world data are available, on operation of food kitchens, health clinics, fair price shops, etc. The other components can be thought of as support systems for the relief work, but the support systems are vital. Mayer notes that "sooner or later, transport becomes the limiting factor in relief" (46). The transportation and logistics system includes entry, storage, and distribution points and all vehicles and personnel needed to convey goods between the points.

Thus, many operations are needed for successful fighting of a food shortage. The information system is central in that each component needs an understanding of its current milieu and its often-changing relationship to the other components. The information linkages have a great bearing on the efficacy of the overall effort.

A note on the feasibility of the system outlined in Figure 1.1 needs to be made. Depending on the governmental structure, such a broad-based plan may not be implementable. Many countries define famine relief as a nutrition problem, and the responsibility for handling nutrition has been split among several sectors or ministries in the government. The sectored bureaucracy is generally not amenable to a sweeping system design (17).

Planning must take into account even more factors than those pictured in Figure 1.1. The issues of overall goals and policies must be addressed to provide a framework for implementation. And the government setting and bureaucracy already in place must be examined as one part of the practical implementation issue. Much wisdom is needed in meeting "soft" impediments--religion, cultural, political, and social obstacles.

One alternative to planning for the existing bureaucracy is revolution (17). Revolution can provide a quick path to a multi-sectored approach to the problem. But whenever revolution is more concerned with the system than with the people, the humanitarian goals of famine relief are ignored. Witness the tragic famine and widespread malnutrition in Cambodia during the past several years (2).

A second opening for a systems approach may occur during an actual disaster. The-e seems to be a relaxing of restrictions during a crisis, allowing new constructs and implementations. This was the case in Bihar in 1968 (58). It may be that one disaster is needed before a broad-based approach to coping with the next disaster can feasibly be implemented.

Information for Planners

The planners in Figure 1.1 desire an information system design that fits the real world situation, is economical, practical, and makes a real difference in relief results. We now examine the planners' information needs in evaluating alternative information systems.

The performance, costs, resource requirements, and critical constraints of the alternative system designs will be of great interest to planners. Performance is related to the stated goals of relief, such as minimizing death or social disruption or the maximization of overall nutritional level. Costs and constraints measure the money, time, personnel, and equipment allocations required.

Several pieces of information could be useful in evaluating alternative information systems. Recommendations for "best" alternatives at several different cost levels would provide budgetary data and a shopping list of proposed systems. "Best" refers to performance based on goals. Additional aids would be an expected system performance level and degree of confidence in each of the recommended alternatives. A description of the minimum system necessary for relief operation is essential for comparison purposes. Knowledge of all possible undesirable results for each alternative would also be helpful to planners. To help determine costs and performance, a list of the real-world variables to be monitored (nutritional level, food storage, water level, etc.) along with suggested measurement statistics is needed. The statistics would include desirable frequency and accuracy of surveys and allowable processing and transmission delays. Knowledge of the effects of varying surveillance frequency and accuracy on system performannce would be an invaluable aid.

There is a need for a general, systematic approach to obtain the information for planners described above. There are lists of nutritional surveillance items with desirable frequency and error attributes (10, 25). These are largely intended for the case of thorough, on-going surveillance and do not single out the most valuable information needs. General lists of possible variables to be monitored in a food shortage also exist (7, 31, 41). But there is not a prioritized crisis variable montoring list with suggested measurement attributes. Neither are there indicators of the relationship between list items and relief system effectiveness. To obtain such a result, the list must be based on information needed to make distribution and allocation decisions. Certainly such a list will be peculiar to each country and crisis. But there probably are items that would be common to all countries' needs.

A wide range of information systems has been mentioned in the literature. A non-existent system resulted in a devastating famine in China during the 1940s; virtually no one, even in the capital, knew of the crisis (63, Chapter 4). At the other extreme, a rapid reporting system designed by a New York consulting firm was a valuable aid in combating the Bihar, India, food shortage of 1967 (6). But the most commonly voiced comment on relief data systems is the lack of reliable and organized information.

The Approach

The diagram of Figure 1.2 presents an approach to design that will systematically lead toward desirable information for planners: data on the real-world variables to monitor, data on measurement attributes for each variable, likely best system alternatives, and the costs and other constraints for each alternative.

There are three major parts to the proposed approach: generation of information system alternatives, computer simulation of relief operation effects, and an optimization procedure to indicate good levels for system parameters. The generation of information system alternatives is a standard part of cost-benefit analysis. It leads to an understanding of the choices available. The common cost-benefit form converts all constraints and potential benefits to a monetary base for comparison purposes. Here, however, constraints $\underline{G}$ could be measured in units of the limiting resource: man-hours, equipment units, etc. The key figures on the benefit side are information quality statistics produced by the given alternatives. Information quality is measured by a set of parameters $\underline{X}$ including processing delays and frequency and error of surveillance. Each environmental variable to be monitored has its own set of $\underline{X}$ parameters. Thus, system alternatives can be characterized by the resources required and information quality produced ($\underline{G}(\underline{X})$ and $\underline{X}$).

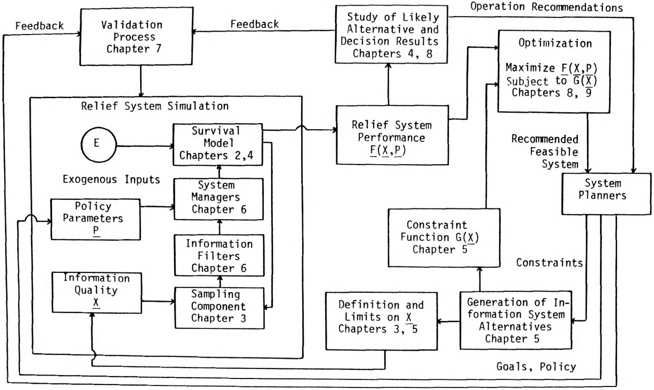


Figure 1.2. A Methodology for Design and Evaluation of Famine Relief Management Information Systems.

The major distinguishing feature of this approach is the use of a computer simulation to evaluate relief system performance. Computer models have often been used in the last three decades as tools in evaluating alternative solutions to economic problems (1, p. 5). Examples of models related the famine relief problem are an agricultural sector simulation in Nigeria and a study of crop-related labor in Bangladesh (1, 21). These studies unearthed some of the root causes of food shortages and some of the problems of food distribution.

It should be noted that a computer simulation does have definite limitations. Not all the important factors affecting relief effectiveness can be included. Biological and physical interactions can be modeled to the extent that the processes can be converted to numerical relationships. But psychological and cultural factors are very difficult to capture, due to the lack of numerical standards. Thus, a simulation can only be one of the analyst's tools in design. There must be appropriate inputs on the role of such intangible or nonnumeric factors as food habits, family ties, and village customs.

The cornerstone of the current simulation effort is a model of the population undergoing a famine. Economic, demographic, and production components must be described. The model must be tuned to adequately depict the environment in which the relief system must operate. A macro view is necessary, at least initially, to adequately describe the scope of the problem.

System management is modeled as a set of decision rules representing policy structure. The rules are activated by the results from surveillance of several key variables. Thus, the intent of policy is to provide guidelines for action based on available information, a

Management Information System. It is assumed that the system managers know the background environment of the country and the goals and framework of the proposed relief system. The model decisions are limited to the rates and timing of relief operations. These policy parameters are dependent on the information received. The data provided to managers are obtained through statistical sampling procedures and information filters. Modeling the sampling and filtering at a macro level allows the simulation of varying data quality without information system details.

The links between alternative generation, system simulation, and optimization are the information quality parameters $\underline{X}$, the policy rate parameters $\underline{P}$, and performance and constraint functions. The output of the computer model is a performance function $\underline{F}(\underline{X},\underline{P})$, where $\underline{F}$ is a vector representing the measurable relief objectives. A constraint function, $\underline{G}(\underline{X})$, is produced by system alternative generation. $\underline{G}$ represents monetary, personnel, and equipment requirements. Off-line analysis work is done to select, for each $\underline{X}$ vector, the information system that best allocates limiting resources.

The functions $\underline{F}$ and $\underline{G}$ are the needed inputs for the third major component of Figure 1.2, the optimization stage. As stated before, information system alternatives are characterized by a set of information quality parameters $\underline{X}$ and a required resources function $\underline{G}$. The simulation portion of the approach describes the effects that $\underline{X}$ will have on desired relief performance $\underline{F}$. The objective of the optimization phase is to maximize performance levels, subject to constraints on the required resources. This problem is difficult to define precisely in the general case and still more difficult to solve analytically. The goals and constraints must be well-defined, and assignment of relief system performance priorities is imperative for computerization.

Valuable insights can be gained even before a precise optimization. By studying the values of model outputs, one can obtain likely results of particular decisions and policy structures. This provides a powerful analysis tool, both for the design of efficient operations and for validation of the computer model. The significant ties between policy structure and the information system, including key environmental variables, can be examined. And simple sensitivity tests can indicate which information quality parameters are most important for surveillance purposes. Knowledge of component linkages and efficient policy structure is a valuable aid to planners that goes beyond basic information system specifications.

The planning process is cyclical in nature as the chart in Figure 1.2 indicates. Model results are continuously compared to real world data and expectations in a validation process. For the model to be a useful tool, system planners must have an understanding of environmental and relief processes and must be satisfied that the model accurately portrays these processes. The model itself is updated, refined, and made more complete as the planning and testing proceed. The analysts' study of system performance leads to a better grasp of the monitoring function. This, in turn, leads to a better definition of policy and information quality parameters $\underline{P}$ and $\underline{X}$.

An information system can provide crucial links between planning, implementation, and on-going operations. In fact, the three are very interrelated. Data capture and processing the data into a useful form are essential for on-going operations and for system implementation. Setting up the machinery to gather and process the data is a planning and implementation function, but requires knowledge of basic operations. This dissertation is mainly a planning tool; it concentrates on establishing a framework for tying a computer simulation to the design of information systems. The operations descriptions are general, echoing the nature of the computer model. Accordingly, the specific data and level of aggregation used here is not immediately transferrable to specific country applications. But the framework for planning should be.

The organization of this dissertation roughly parallels the sequence of events leading to the development of the approach of Figure 1.2. An application of the approach to a hypothetical country is followed through the individual steps, including major findings, pitfalls, and areas for further research. Part I covers the generation of information system alternatives and relief system simulation, along with the validation process and a study of initial model results. Part II examines the optimization techniques applicable to the problem. And Chapter 10 presents major results and conclusions, notes potential advantages and disadvantages of the approach, and outlines several areas for further research.

Chapter 2 describes the basic survival model designed by Dr. T. J. Manetsch (38). The addition of a sampling component to simulate information inputs to system managers is covered in Chapter 3, along with a detailed description of the $\underline{X}$ parameters used in the study. Initial model results and subsequent policy changes are discussed in Chapter 4. Information system alternatives with related costs and $\underline{X}$ values are examined in Chapter 5. The roles of the system manager and information filters are contained in Chapter 6. And Chapter 7 concludes Part I with a summary of model and approach validation techniques.

The optimization section is divided into two chapters. The actual optimization work for the current application is covered in Chapter 9. Chapter 8 discusses pre-optimization work, methods for identifying the most sensitive $\underline{X}$ and $\underline{P}$ parameters. By limiting the number of parameters, optimization techniques are easier and less costly to apply.

Considering the cyclical nature of this systems approach, the order of events in Part I described above is certainly not compulsory. The simulation and system alternatives sections can be developed simultaneously, as can the components within the model. However, Part I completion should logically precede Part II. And the sensitivity work of Chapter 8 should precede the optimization of Chapter 9.

Summary

This approach is a proposed design. Much work is needed for implementation, this dissertation is only an initial pass. The approach is not a guaranteed solution to the whole problem of famine relief. The many complex interactions require well-defined objectives and tight coordination of efforts between the many subsystems depicted in Figure 1.1.

The question of whether famine relief efforts should be pursued is not specifically addressed here. It is assumed that man has an obligation to relieve needless suffering where he can. Certainly a food shortage gives enough advanced warning that some sort of planning is imperative.

CHAPTER II

THE BASIC SURVIVAL MODEL

The survival model discussed in this chapter was created by Dr. T. J. Manetsch and has been described by him elsewhere (38). A general description and many of the important modeling features are included here to provide necessary background material for the development of succeeding chapters.

A computer simulation is an excellent tool for the systematic study of famine relief because the extremely complex nature of the problem requires analysis of several large, interconnecting, dynamic systems. Demographic, economic, transportation, communication, and system management components, and their interactions defy simple examination. The computer allows the testing of many distinct strategies and system alternatives in a relatively short amount of time; performance can be estimated without experimentation in real food crises. And a simulation explores the process and structure of relief operations and responses as well as providing numerical calculations.

This survival model was constructed to study alternative strategies for combating a food crisis and to shed light on areas for further work. In particular, a rationing strategy and the question of optimum timing and quantities of international food aid were examined (38). Suggested research areas included the impact of information quality on government decision making and the design of an overall information

system
tion.
well a
ficall
tinues
lowed
a shor

exami
inter
of ov
are r
done
ing
quat
stru

naul
the
(war
age
with
tio
har
the

system for famine relief, topics that are addressed in this dissertation. Chapter 3 contains a description of an information component as well as several modifications of the basic model to allow it to specifically address the information systems problem. This chapter continues with an overview of the scenario and scope of the model, followed by a more detailed account of interesting modeling features and a short summary.

The Scenario: a Country Facing a Short Term Famine

The model describes a country on the brink of a food crisis and examines the demographic, economic, nutritional, and relief operation interactions over a one to two year time span. The important problems of overpopulation and underproduction, possible causes of the crisis, are not addressed. Rather, the scope is restricted to what can be done with available resources when a severe famine occurs. The modeling is of a hypothetical country, so the simulation is not yet adequate for use in any specific nation. But the general processes and structures important to relief work can be discovered.

The country has a regular food deficit and must import grain annaully, but a balance of payments problem is assumed which restricts the amount of imports available on short notice. The particular cause (war, crop failure, natural disaster, drought, etc.) of the food shortage is not specified; the country begins the simulation in Janaury with storage levels well below the amount needed to feed the population through the next harvest period in mid-June. A second, larger harvest occurs in October. Thus, the severity of the crisis is set by the initial conditions on total grain storage, specifically the amount in rura

age oc

dition

condit

pond t

values

F

rural.

stocks

sumer.

at in

class

out.

eithe

witho

and t

dynar

nutr

and

harv

comp

the

port

ava

in rural private storage (RSTOR). The real "crunch" of the food shortage occurs just before the first harvest. There are other initial conditions which influence system performance: population sizes, crop conditions, nutrition levels, etc. These values must be set to correspond to actual values in any specific application; currently, the values are estimated from South Korean data.

Four population classes are included, three urban classes and one rural. The rural class is assumed to have most of the available food stocks, which it normally sells in the marketplace to the urban consumer. One class, the urban rich, is generally able to buy food, even at inflated prices. The urban poor constitute the remaining two classes and are divided into those with rural relatives and those without. In the event of food shortages, the poor with rural relatives can either migrate to the farms or receive aid from relatives. The poor without rural relatives are most vulnerable.

The consumption patterns, nutritional requirements, storage levels and births and deaths peculiar to each population class are modeled dynamically. In addition, malnutrition levels and deaths due to malnutrition are calculated. These portions of life relevant to famine and famine relief work are simulated.

The production component calculates the extent and timing of the harvests and increases rural private storage accordingly. The market component computes sales and prices based on supply and demand of the population groups.

The government component interacts with each of the other model portions through decision rules on allocation and distribution of available grain. The decisions include the rates and "triggers" to use

tor

gen

ove

tio

por

for

and

in

re

us

ti

ar

b

s

a

t

a

use for emergency actions: acquisitions from the rural (hoarding) sector, sales of government storage in the market, implementation of emergency feeding programs. The rules are constructed on the basis of an overall relief strategy, such as strong price controls or enforced rationing of available food. An additional part of the government component is the data acquisition procedure needed to obtain necessary information values such as nutritional levels, private storage levels and population size.

The world outside the country is exogenous to the model, the only interactions coming through international food aid and grain imports received by the stricken nation.

Each of the processes mentioned here has been modeled through the use of a wide range of techniques including distributed and exponential delays, numerical integration, maximum functions, table functions, and arithmetic computations. Although the detailed operations may not be of general interest, the main equations and techniques are described in the next section and referred to in later chapters.

Important Modeling Features

The demographic, economic, nutritional, and production components are highly interconnected. Thus, the format of this discussion will be to follow the food chain through the model, beginning with nutritional and consumption considerations and moving to production, the marketplace, and storage facilities. The information needed to monitor the food chain processes provides a natural link to the government data gathering and decision making component. Two distinct policy strategies and the information estimation structure will be described. Figure

2.1

flo

Nut

mea

one

tic

and

the

(A

ti

wi

t

t

2.1 indicates the main components of the food chain along with the flows of food and related information.

Nutritional Level

A cornerstone in analyzing the effects of a food crisis is the measurement of nutritional level of the population. Certainly, this is one of the main areas of concern in evaluating famine relief operations and is one of the information links between population groups and decision makers in Figure 2.1. The basic quantified form used in the survival model is that of accumulated, per-capita, nutritional debt (ANUTDP), which is calculated in Equation 2.1 as the difference over time between required normal food intake and actual consumption.

$$ANUTDP_j(t) = ANUTDP_j(0) + \int_0^t (RNUTP_j(s) - PCONS_j(s))ds \qquad (2.1)$$

where:

ANUTDP = accumulated per-capita nutritional debt (MT/person)

RNUTP = current required nutritional intake (MT/person-year)

PCONS = per-capita consumption (MT/person-year)

j = index on population classes.

All food types are combined to give a "total energy" viewpoint to the nutritional calculations. This eliminates unneeded complexity for the gross, macro problems addressed here, but obscures the vital details of actual relief work: prescribing diets, ordering acceptable foodstuffs, etc. Quantities of food are converted to grain equivalents; the units used throughout the model are metric tons of grain equivalent.

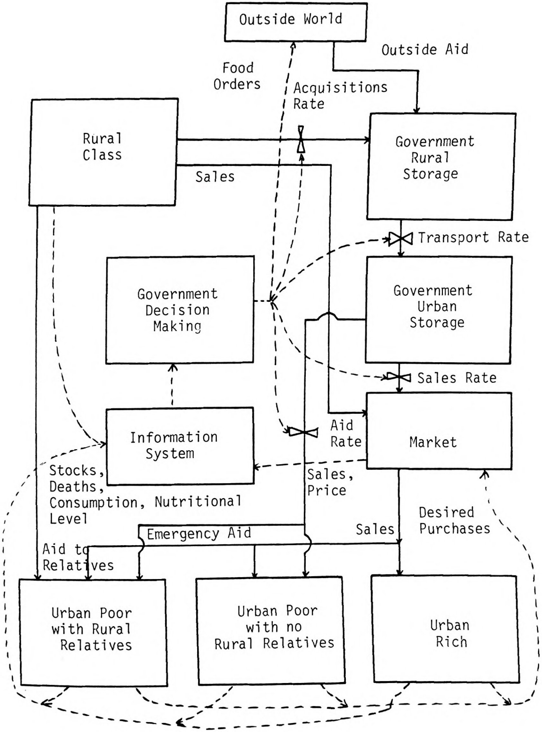


Figure 2.1. Food and Information Chains
in Preliminary Survival Model.

rest

leve

nutr

poin

phys

incr

deat

the

tery

as

ed

whe

De

th

ma

la

c

Two physiological facts form the basis for the modeling of the rest of the nutrition equations. First, as an individual's nutritional level drops (nutritional debt increases), weight drops, and required nutritional intake (RNUTP) decreases, up to a point. That is, up to a point, the less one weighs, the less one needs to eat. The second physiological fact is that the probability of death due to malnutrition increases with nutritional debt. It should be noted that rarely is death attributable directly to starvation. But malnutrition weakens the body and makes one highly susceptible to disease, especially dysentery and diarrhea (53). Deaths due to malnutrition are calculated here as those that occur above the normal death rate.

Required nutrition falls as nutritional debt increases, as computed in Equation 2.2.

$$RNUTP_j(t) = \max(RNUTPN - UK4*ANUTDP_j(t)\ ,\ UK5) \qquad (2.2)$$

where:

RNUTP = required nutrition per person (MT/person-year)

RNUTPN = normal required nutrition per person (MT/person-year)

UK4 = parameter; rate of effect of nutritional debt on required nutrition (yr^{-1})

UK5 = minimum life sustaining nutrition (MT/person-year)

ANUTDP = accumulated nutritional debt (MT/person)

j = index on population classes.

Death Rates

The assumption is made, based on the central limit theorem, that the probability of death due to malnutrition follows a cumulative normal distribution on nutritional debt. This holds as long as the population starts with little or no malnutrition. Each urban and rural class has its own probability distribution. Specific numerical data are

sume

man

leve

the

Henc

cura

calc

whe

are estimated from controlled empirical studies (26). It is also assumed that deaths occur only when nutritional debt increases. The human body adapts to the chronic malnutrition represented by a constant level of nutritional debt. But the modeling is not yet adequate for the case of returning to a malnourished state following recovery. Hence, long term (greater than two years) simulations will not be accurate. The probability functions, death rates and total deaths are calculated by Equations 2.3.

$$ANTDPM_j(t) = \max(ANTDPM_j(t - \Delta t),\ ANUTDP_j(t)) \qquad (2.3a)$$

$$PDTH_j(t) = F2(ANTDPM_j(t)) \qquad (2.3b)$$

$$PDTH_j(t - \Delta t) = F2(ANTDPM_j(t - \Delta t)) \qquad (2.3c)$$

$$DTHSM_j(t) = \max(\ (PDTH_j(t) - PDTH_j(t - \Delta t)) * (POP_j(t) + TDTHSM_j(t)\ ),\ 0.0) \qquad (2.3d)$$

$$DRM_j(t) = DTHSM_j(t)\ /\Delta t \qquad (2.3e)$$

$$TDTHSM_j(t) = \sum_k DTHSM_j(k * \Delta t) \qquad (2.3f)$$

where:

ANTDPM(t)	=	maximum per-capita nutritional debt in the interval (0,t) (MT/person)
ANUTDP	=	accumulated nutritional debt (MT/person)
PDTH(t)	=	probability of death due to malnutrition in the interval (0,t)
F2	=	cumulative normal distribution function
DTHSM(t)	=	deaths due to malnutrition in the interval (t - Δt, t) (persons)
POP	=	population (persons)
DRM	=	death rate due to malnutrition (persons/year)
TDTHSM	=	total deaths due to malnutrition (persons)
j	=	index on population class
k	=	index on discrete time intervals Δt in model.

rat

fec

Gra

co

to

la

be

ar

or

t

a

The malnutrition death rate, DRM, is added to the normal death rate to arrive at a total death figure. The birth rate is also affected by nutritional level, falling with consumption.

Grain Storage

Physiological modeling has the same form for all classes, but the consumption patterns differ for the rural and urban populations, due to their distinct food acquisition and storage habits. The rural population is self-sustaining and stores quantities to last through the beginning of the next harvest period. The urban classes, both rich and poor, buy supplies at regular intervals and expect to make their on-hand storage last for a much shorter time than do their rural countrymen. The difference in storage habits can be seen in Equations 2.4a and 2.4b, representing urban and rural private storage, respectively.

$$USTOR_j(t) = USTOR_j(0) + \int_0^t (UPUR_j(s) - CONSU_j(s) + EMFSL_j(s) = EMFDGL_j(s))ds \tag{2.4a}$$

$$RSTOR(t) = RSTOR(0) + \int_0^t (RH(s) - RSALES(s) - CONSR(s) - EMFSU(s) - GAQ(s))ds \tag{2.4b}$$

where:

USTOR = urban private food storage (MT)

RSTOR = rural private food storage (MT)

UPUR = urban market purchases (MT/year)

CONSU = urban market purchases (MT/year)

CONSR = rural consumption (MT/year)

EMFSU = emergency food sent to urban relatives (MT/year)

EMFSL = emergency food received from rural relatives (MT/year)
(EMFSL is lagged version of EMFSU)

EMFDGL = emergency food received from government programs (MT/year)

RH = harvest yield (MT/year)

RSALES = rural sales in market (MT/year)

GAQ = government acquisitons from rural stores (MT/year)

j = index on urban classes.

Note that urban food sources are purchases and emergency relief, while harvests provide the only source for the rural class. Urban purchases and rural sales are results of market activity, to be discussed later. Government acquisitions and emergency food programs are also described later, as part of the decision making component.

Given the differing time scales of urban versus rural storage habits, it is clear that their consumption patterns are based on different information inputs. Both groups have a desired base consumption level computed as the normal required nutrition rate (RNUTPN) plus a constant times current nutritional debt, to make up for past malnourishment. But the desired level is tempered by a food availability factor which differs substantially for urban and rural classes.

The rural individuals know their consumption requirements and the expected time of the next harvest. They plan to stretch their food stocks accordingly. Thus, the rural food availability factor (FR1) is determined as an increasing function of the ratio (XFR1) of current storage to storage desired. The form of the function is given in Figure 2.2a. Both XFR1 and FR1 are dimensionless variables.

Note that if current storage exceeds desired storage, ratio XFR1 is greater than one and consumption can proceed at desired levels. But for XFR1 values below one, self-imposed rationing occurs to make

FR1
rural
food
avail-
abil-
ity
factor

FU1
urban
food
avail-
abil-
ity
factor

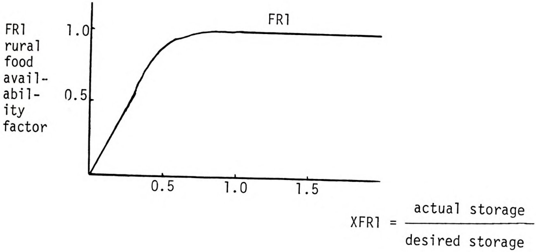


Figure 2.2a. Rural Food Availability Factor as a Function of Actual to Desired Storage Ratio.

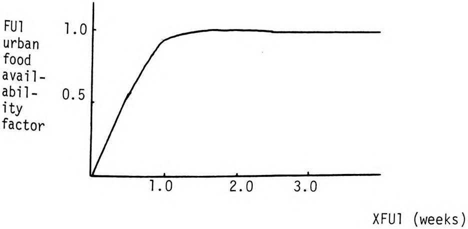


Figure 2.2b. Urban Food Availability Factor as a Function of Time Availability of Current Stocks.

stocks

Chapt

a sev

of XF

too c

crisi

the r

time

priv

2.5,

the

as a

ure

the

whe

stocks last. During the course of verification work, discussed in Chapter 4, it was discovered that the concave shape of this function is a severe impediment to minimizing total deaths. Especially for values of XFR1 greater than 0.5, consumption is too great, depleting stocks too quickly and causing increased deaths in the latter months of the crisis.

The time span for personally desired storage is much shorter for the urban classes, and no convenient time-frame exists for them as does time-until-harvest for the rural population. But given current urban private stocks and nutritional needs, one can determine, using Equation 2.5, the length of time (XFU1) before stocks will be exhausted. Then the food availability factor for urban classes (FU1) can be computed as a function of XFU1. The shape of the function is pictured in Figure 2.2b. Note that virtually no consumption cutbacks are made unless the time availability of current stocks is less than one week.

$$XFU1_j(t) = \frac{USTOR_j(t)}{RNUTP_j(t) \ * \ POP_j(t)} \qquad (2.5)$$

where:

XFU1 = time availability of current stocks at current consumption rate (year)

USTOR = personal storage (MT)

RNUTP = current nutrition required (MT/person-year)

POP = population (persons)

j = index on urban population classes.

Emergency Aid to Relatives

The emergency food sent from rural individuals to poor urban relatives, EMFSU, was mentioned in the discussion on private storage (Equations 2.4). The amount of food sent is based on availability in the rural sector (using FR1 again) and on the relative nutritional levels of the two groups. Aid will be sent at a rate proportional to the perceived difference in the groups' nutritional debts and the consumption level of the urban relatives. Equation 2.6 describes the process. The amount of grain actually received by the urban relatives (EMFSL) is computed simply as a first order exponential delay of the amount sent, to allow for transportation lags. The form of the delay is the same as described in Equations 2.16.

$$EMFSU\ (t) = \max\left(\left(FR1(t)*(RK1*(PANUTD(t) - RNUTDP(t)) + RK2*\frac{dPANUTD(t)}{dt}\right) * POP_2(t)),0.0\right) \tag{2.6}$$

where:

EMFSU = emergency food sent to urban relatives (MT/year)

FR1 = rural food availability factor

PANUTD = perceived per-capita nutritional debt of urban relatives (MT/year)

RNUTDP = rural nutritional debt per-capita (MT/person)

RK1, RK2 = parameters used to tune equation to real conditions

POP_2 = population of urban poor class with rural relatives (persons).

Food Production

The nutritional level of an individual is largely determined by consumption patterns, and these two items are at the end of the food chain. At the beginning is food production, which takes place in the rural areas

the harvest

The d

figure. O

vated acre

late the v

in mid-Jun

these desi

input to a

set of n f

harvest ra

an nth-ord

flow, nume

estimate

Harv

duals the

based on

fered if

Sales inc

cating fo

The

mand depe

outside a

supply ex

rich, wi

given pr

rich are

rural areas. The model computes the total crop size, the timing of the harvests, and the distribution of the harvest over time.

The different actual crops are aggregated into one grain-equivalent figure. Output is calculated as the product of yield per acre, cultivated acreage, and a weather factor which could be randomized to simulate the vagaries of agricultural production. Harvests are set to start in mid-June and October with the later crop's being the larger. At these designated times, the calculated grain output is fed as a pulse input to a distributed delay process (40, Chapter 10). The delay is a set of n first order differential equations whose output is a stream of harvest rates (see Equations 2.18). The time series of rates follows an nth-order Erlang distribution. Since the delay process conserves flow, numerical integration of the delay rates produces an accurate estimate of total output.

Harvested grain enters rural, private storage. The rural individuals then sell grain on the market with quantities offered (RSUP) based on consumption needs and the price of grain. No sales are offered if the rurals realize they do not have enough for themselves. Sales increase with high prices, although rapidly rising prices, indicating food shortages, depress rural sales.

The buyers in the market place are the urban classes. Their demand depends on desired consumption, price level, and the amount of outside aid received from rural relatives or government sources. When supply exceeds demand, all classes buy their desired amounts. But the rich, with higher disposable income, can pay higher prices and are given preference when demand exceeds supply. Once the demands of the rich are met, the remainder is split among the poor classes.

Price Level

Price is dete

2.7, a classical W

$$\frac{dPFD(t)}{dt} = CM$$

*

where:

PFD = food

UDEM = urban

GSLSD = gover

RSUP = rural

DEM_0 = avera

CM1 = marke

j = inde

Government Decisi

As seen in F

foreign imports (

chases from the r

stores as a price

lization calculat

of the policy str

indicate that it

supplies are exha

GSLSD(t) = (

where:

Price Level

Price is determined by supply and demand levels as in Equation 2.7, a classical Walrasian market price mechanism (54).

$$\frac{dPFD(t)}{dt} = CM1*\left(\sum_{j=1}^{3} UDEM_j(t) - GSLSD(t) - RSUP(t) \right) * PFD(t) / DEM_0 \qquad (2.7)$$

where:

PFD = food price (monetary unit/metric ton)

UDEM = urban food demand (MT/year)

GSLSD = government desired domestic sales (MT/year)

RSUP = rural sector desired sales (MT/year)

DEM_0 = average aggregate demand (MT/year)

CM1 = market price response coefficient

j = index on urban population classes.

Government Decision Points

As seen in Figure 2.1, the government acquires food either through foreign imports (GIMP), emergency food aid (EMFINT), or direct purchases from the rural sector (GAQU). Sales are made from government stores as a price control mechanism. Equation 2.8 describes the stabilization calculation used. Price control is the main feature of one of the policy strategies to be discussed later, and simulation results indicate that it is an effective allocation measure until government supplies are exhausted (38).

$$GSLSD(t) = (PFD(t) - PFDD) / PFDD + GNSLS \qquad (2.8)$$

where:

GSLSD = gove

PFD = curre

PFDD = desi

GNSLS = norma

CGP = polic

Grain storage

simulation. Equat

ing the levels of

rated into rural a

Rural storage is g

than that of short

levels of governme

transportation lin

government decisio

GSR(t) = GSR

- R

GSU(t) = GSU

where:

GSR = gov

GSU = gov

GIMP = imp

EMFINT = in

GAQU = go

REMFDG = em

GSRU = gr

GSLSD = government desired domestic sales (MT/year)

PFD = current food price (monetary unit/MT)

PFDD = desired food price (monetary unit/MT)

GNSLS = normal level of government domestic sales (MT/year)

CGP = policy control parameter (dimensionless).

Grain storage is a vital component of the food chain in any dynamic simulation. Equations 2.4 have described the inputs and outputs affecting the levels of personal storage. Government grain stocks are separated into rural and urban components, dependent on physical location. Rural storage is generally long term and, thus, its capacity is higher than that of short term urban stores. Equations 2.9 calculate the levels of government storage, based on input and output rates. The transportation links between rural and urban sites involve an important government decision, the rate of movement of grain (see Equation 2.10).

$$GSR(t) = GSR(0) + \int_0^t (GIMP(s) + EMFINT(s) + GAQU(s) - REMFDG(s) - GSRU(s))ds \tag{2.9a}$$

$$GSU(t) = GSU(0) + \int_0^t (GFRRU(s) - GSLS(s) - EMFDG(s))ds \tag{2.9b}$$

where:

GSR = government rural grain storage (MT)

GSU = government urban grain storage (MT)

GIMP = imported grain (MT/year)

EMFINT = international emergency aid (MT/year)

GAQU = governmental acquisitions from rural sector (MT/year)

REMFDG = emergency food aid to rural sector (MT/year)

GSRU = grain sent from rural to urban storage (MT/year)

GFRRU = gra
GSRU

GSLS = gove

EMFDG = gove

The general f

rural sector; impo

place determined b

vate and governmen

level. When a foo

sector hoards its

Without substantia

depleted as it mus

prices soar, and t

rural relatives re

and many die.

Relief Strategies

The governmen

response to such a

been simulated and

used is to minimi

sible. A second g

end of a year, is

GFRRU = grain arriving at urban storage (lagged value of GSRU) (MT/year)

GSLS = government domestic sales (MT/year)

EMFDG = government emergency aid to urban poor (MT/year)

The general food chain is modeled to include production by the rural sector; imports by the government sector; sales in the market place determined by consumption needs, prices, supply, and demand; private and government storage; consumption; and the resulting nutritional level. When a food crisis occurs, the chain breaks down. The rural sector hoards its small supplies, not offering grain in the market. Without substantial international aid, the government's supplies are depleted as it must sell grain to keep prices down. Sales decrease, prices soar, and the urban poor are unable to buy food. Those with rural relatives receive some aid, but the poor with no relatives starve and many die.

Relief Strategies

The government decision making component simulates strategies of response to such a food crisis. Two particular relief designs have been simulated and tests run to check their performance. The objective used is to minimize total deaths. Other objectives are obviously possible. A second goal, that of minimizing total nutritional debt at the end of a year, is considered in later chapters.

One plan for

Equation 2.8 to op

prices are too hig

large number of de

program is ineffec

price control also

government wants t

the price stabiliz

which increases de

nutritional debt (

The second mo

spreading nutritio

equalization of nu

of needing less fo

be much more effec

The decision

is to be done, whe

five activities w

the rural sector,

urban poor, forei

rural to urban si

ger" used to decl

The approach

strategy has grea

mated and compare

difference dete

commonly called

One plan for relief is to allow the price control mechanism of Equation 2.8 to operate, providing free emergency aid to the poor when prices are too high. Unfortunately, this strategy does not reduce the large number of deaths in the urban poor classes. The emergency aid program is ineffectual since the lack of grain signaling the failure of price control also precludes distribution of free food. So when the government wants to aid the poor, it cannot. The main computation in the price stabilization strategy is a modification of Equation 2.8 which increases desired government sales (GSLSD) with perceived urban nutritional debt (TPUND).

The second modeled strategy is based on rationing available food, spreading nutritional debt evenly across all classes. Rationing and equalization of nutritional debt are based on the physiological process of needing less food as weight drops. This strategy has been shown to be much more effective than the price control scheme above (38).

The decision rules to implement a relief plan must stipulate what is to be done, when to do it, and at what rate. Figure 2.1 indicates five activities which the government can influence: acquisition from the rural sector, sales from government stocks, emergency aid to the urban poor, foreign import orders, and the transportation rate from rural to urban sites. An additional item to be discussed is the "trigger" used to declare existence of a food crisis.

The approach used in constructing decision rules for the rationing strategy has great generality. Key information quantities are estimated and compared to desired values. The direction and size of the difference determines the type and level of relief response. This is commonly called a closed loop feedback control (55, Chapter 6). A simple example sh

port of governmen

trol loop is inst

storage (GSRD).

and compared with

since government

values, and there

difference (GSR -

rate at which the

to insure non-neg

GSRU(t) = ma

where

GSRU = gover

GSR = gover

GSRD = desir

CG1 = param

Recall that

Thus, if GSR is g

ence. If GSR is

stores to increas

Government

control loop. Th

orders is compar

If supplies exce

the country cann

storage and impo

simple example should help explain the concept. Rural-to-urban transport of government grain must take place at some rate. A feedback control loop is instituted by setting a desired level of government rural storage (GSRD). The size of actual rural storage (GSR) is ascertained and compared with GSRD. (The model assumes perfect knowledge of GSR, since government supplies are well known compared to other estimated values, and there are procedures extant for their measurement.) The difference (GSR - GSRD) is multiplied by a parameter designating the rate at which the gap will be narrowed. A maximum function is included to insure non-negative transport rates. The result is equation 2.10.

$$GSRU(t) = \max\ (CG1*(GSR(t) - (GSRD), 0.0) \qquad (2.10)$$

where

GSRU = government rural-to-urban transport rate (MT/year)

GSR = government rural storage (MT)

GSRD = desired government rural storage (MT)

CG1 = parameter determining rate of transport ($year^{-1}$).

Recall that increasing GSRU decreases GSR, from Equation 2.9a. Thus, if GSR is greater than desired, GSRU works to reduce the difference. If GSR is less than desired, no food is sent, allowing rural stores to increase through imports and acquisitons.

Government import orders are determined using a similar feedback control loop. The total amount of government storage plus previous orders is compared to desired storage plus the expected amount of sales. If supplies exceed demands, no orders are made. But, in general, since the country cannot produce enough to feed itself, demand exceeds actual storage and imports are ordered.

Declaration o

relief operations

warning signals ex

capita storage def

age level, subtrac

difference by the

given in Equations

level, an emergenc

runs, although a s

ETDSTG(t) =

ETSTG(t) = G

EDPC(t) = (E

Where:

ETDSTG - est

ETSTG = est

EDPC = est

TTSH = ti

SF = sa

ETPOP = es

RNUTPN = no

EIMP = es

GSR = go

GSU = go

ERSTOR = es

Declaration of a famine is an important timing consideration, since relief operations will begin with the announcement. Numerous early warning signals exist (25, 53). The "trigger" used here is the per-capita storage deficit. It is calculated by computing a desired storage level, subtracting estimated actual total storage and dividing the difference by the estimated population total. The computations are given in Equations 2.11. If the final figure (EDPC) is above a pre-set level, an emergency is declared. (The level 0.0 was used in simulation runs, although a small negative value may be better.)

$$ETDSTG(t) = (TTSH(t) + SF)*ETPOP(t)*(RNUTPN-EIMP(t) / ETPOP(t)) \qquad (2.11a)$$

$$ETSTG(t) = GSR(t) + GSU(t) + ERSTOR(t) + \sum_{j=1}^{3} USTOR_j(t) \qquad (2.11b)$$

$$EDPC(t) = (ETDSTG(t) - ETSTG(t))/ETPOP(t) \qquad (2.11c)$$

where:

ETDSTG - estimated total desired storage (MT)

ETSTG = estimated total storage (MT)

EDPC = estimated storage deficit per-capita (MT/person)

TTSH = time until start of next harvest (years)

SF = safety factor for time of harvest (years)

ETPOP = estimated total population (persons)

RNUTPN = normal nutritional requirement (MT/person-year)

EIMP = estimated imports (MT/year)

GSR = government rural storage (MT)

GSU = government urban storage (MT)

ERSTOR = estimated rural private storage (MT)

EUSTOR = esti

j = inde

Notice that d

new crop is ready,

capita consumption

at the time of des

tion work, as expl

The aim of th

across population

government can use

food programs (EMF

nutritional debts

and the average a

back control loop

ARNUT is cal

amount of availab

and across the ti

cluded since thos

use of TTSH and a

conditions.

ARNUT(t) = (

where:

ARNUT = aver
year

ETSTG = est

TTSH = tim

SF = saf

EUSTOR = estimated urban private storage (MT)

j = index on urban population classes.

Notice that desired storage is the product of the time until the new crop is ready, the estimated number of people, and the desired per-capita consumption rate. The use of TTSH plus a constant safety factor at the time of desired storage is too crude an estimate for optimization work, as explained in Chapter 4.

The aim of the rationing strategy is to equalize nutritional debt across population classes. The three main control activities that the government can use are acquisitions (GAQU), sales (GLSLDU), and free food programs (EMFDGU). The specific decision rules use accumulated nutritional debts, private storage levels of the population classes, and the average available rate of nutrition per-capita (ARNUT) in feedback control loops.

ARNUT is calculated in Equation 2.12 by estimating the total amount of available food and dividing it equally among the citizens and across the time until the next harvest. Estimated imports are included since those supplies are expected. As mentioned earlier, the use of TTSH and a constant SF does not work well under optimization conditions.

$$ARNUT(t) = (ETSTG(t)/(TTSH(t) + SF) + EIMP(t))/ETPOP(t) \quad (2.12)$$

where:

ARNUT = average available per-capita nutrition rate (MT/person-year)

ETSTG = estimated total storage (MT)

TTSH = time until harvest start (years)

SF = safety factor for harvest timing (years)

EIMP = estim

ETPOP = estim

If all popula

equal nutritional

would insure equal

levels are unequal

ernment calculates

on ARNUT and know

used as target le

debt across class

is used to equali

sales rate evens

some of the urban

food program is u

poor classes. No

back loops and AR

GAQU(t) = ma

+

GSLSDU(t) =

$EMFDGU_j(t)$

EIMP = estimated imports (MT/year)

ETPOP = estimated total population (person).

If all population classes started with equal levels of storage and equal nutritional debt levels, consumption of food at the rate ARNUT would insure equalization of the rationing strategy. But since initial levels are unequal, additional control variables are needed. The government calculates desired private storage levels for each class based on ARNUT and knowledge of consumption habits. These desired values are used as target levels in one feedback loop. Comparison of nutritional debt across classes forms a seond feedback loop. The acquisition rate is used to equalize rural versus average urban nutritional debt and the sales rate evens the debts for rich versus poor urban classes. Since some of the urban poor receive aid from rural relatives, the emergency food program is used to equalize nutritional debt across the two urban poor classes. Notice in Equations 2.13, 2.14 and 2.15 the use of feedback loops and ARNUT.

$$GAQU(t) = \max(GC30*(ERSTOR(t) - GRSTRD(t)), 0.0) + CG36*(AEUNDP(t) - ERNTDP(t))*PR(t) \qquad (2.13)$$

$$GSLSDU(t) = ARNUT(t)*(PU_3(t) + CG31*(PU_1(t) + PU_2(t)) + CG32*(EATNDP_3(t) - \frac{EATNDP_1(t) + EATNDP_2(t)}{2.0} *PU_3(t) + CG34*(GUSTRD_3(t) - EUSTOR_3(t)) \qquad (2.14)$$

$$EMFDGU_j(t) = ARNUT(t) * PU_j(t) + CG27*(EATNDP_j(t) - \frac{EATNDP_1(t) + EATNDP_2(t)}{2.0} \qquad (2.15)$$

$*PU_j($

where:

GAQU = g

GSLSDU = g

EMFDGU = g

ERSTOR = e

EUSTOR = e

GRSTRD = g

GUSTRD = g

ERNTDP = e

EATNDP = e

AEUNDP = a

ARNUT = a

PR =

PU =

CG30,CG34 =

CG36,CG32,
CG27 =

j =

Each of the
are used to adjus
etc.) so that the
ences between con
figures are used
values (to be dis

$$*PU_j(t) + CG34*(GUSTRD_j(t) - EUSTOR_j(t))$$

where:

GAQU = government acquisitions from rural sector (MT/year)

GSLSDU = government desired domestic sales (MT/year)

EMFDGU = government emergency food (MT/year)

ERSTOR = estimated rural private storage (MT)

EUSTOR = estimated urban private storage (MT)

GRSTRD = government desired rural private storage (MT)

GUSTRD = government desired urban private storage (MT)

ERNTDP = estimated rural nutritional debt (MT/person)

EATNDP = estimated urban nutritional debt (MT/person)

AEUNDP = average estimated urban nutritional debt (MT/person)

ARNUT = average available rate of nutrition (MT/person-year)

PR = rural population (persons)

PU = urban population (persons)

CG30,CG34 = control parameters for private storage feedback loops ($year^{-1}$)

CG36,CG32, CG27 = control parameters for nutritional debt feedback loops ($year^{-1}$)

j = index on urban population classes (j=1 signifies poor with no relatives, j=2 signifies poor with relatives, j=3 signifies rich class).

Each of the control loops contains a population multiplier. These are used to adjust the units of the control parameters (CG36, CG34, etc.) so that the parameters represent the rate at which the differences between compared values will be narrowed. The exact population figures are used in these basic model equations although estimated values (to be discussed next) would give a more accurate portrayal of the decision proces

will be dependent c

are added.

Information for Ma

In any relief

known. Uncertaint

certain their effe

Three estimation f

types of processes

interval between t

similar delay with

of data acquisitio

simulate large g

Once a decis

tions, government

implement the dec

each variable and

2.16. This type

food aid sent to

$VARL_{ij}(t) =$

where:

VARL = lagg

VARU = unla

DEL = aver

Δt = time

the decision process. Note also that the control parameters' values will be dependent on each other because the distinct feedback loops are added.

Information for Management

In any relief activities, very few information items are perfectly known. Uncertainty and error are introduced in the model to help ascertain their effects on performance and make the model more realistic. Three estimation forms are used to allow for simulation of different types of processes. A first order exponential delay describes the time interval between the making of a decision and its implementation. A similar delay with randomness models the lag time and measurement error of data acquisition. And an nth-order distributed delay is used to simulate large grain shipments.

Once a decision rule is invoked, desired values of grain acquisitions, government sales, etc., go to the programs that will physically implement the decision. The organizational and communication lags for each variable and class (if necessary) are represented by Equation 2.16. This type of delay is also used to simulate the transport lag of food aid sent to urban relatives (Equation 2.6).

$$VARL_{ij}(t) = VARL_{ij}(t - \Delta t) + \frac{\Delta t}{DEL_{ij}} * (VARU_{ij}(t) - VARL_{ij}(t - \Delta t) \qquad (2.16)$$

where:

VARL = lagged implemented value of variable

VARU = unlagged desired value of variable

DEL = average implementation delay (years)

Δ t = time increment of discrete modeling process (years) i = index

j = index

Information i

private storage le

variable, by class

and measurement er

variable RR cause

time increment Δ

rors are added ov

effect on EST is

error is compound

$EST_{ij}(t) = E$

-

where:

EST = estima

NEW = actual

DEL = averag

SD = standa

RR = unifo

Δ t, i, j =

In transpor

go at its destin

value. This is

tions 2.18 (40 C

i = index on variables

j = index on population classes.

Information items required by system managers include population, private storage levels, and nutritional debt. Each sampled population variable, by class, is estimated with appropriate transmission delays and measurement error, according to Equation 2.17. The uniform random variable RR causes a zero mean uniformly distributed error term at each time increment Δt. And since Δt is small, many such independent errors are added over the course of a simulation run. So the cumulative effect on EST is a zero mean, normally distributed random error. This error is compounded by the deviation from NEW caused by the delay term.

$$EST_{ij}(t) = EST_{ij}(t - \Delta t) + ((1. + SD_i * RR) * NEW_{ij}(t) - EST_{ij}(t - \Delta t)) * \frac{\Delta t}{DEL_{ij}} \qquad (2.17)$$

where:

EST = estimated information value

NEW = actual information value

DEL = average delay time in information transmission (years)

SD = standard deviation of measurement error (same units as NEW)

RR = uniformly distributed random variable (-1/2, 1/2)

Δt, i, j = as in Equation 2.16.

In transporting large quantities of grain, the arrival of the cargo at its destination will be distributed in time around some mean value. This is modeled by the series of first order differential Equations 2.18 (40 Chapter 10). The two specific distributed delays in the government componen

grain and the arriv

ing procedure is us

nent. The input is

$$\frac{dr_{1j}(t)}{dt} = \frac{\ldots}{D\ldots}$$

$$\frac{dr_{2j}(t)}{dt} = \frac{K\ldots}{D\ldots}$$

.

.

.

$$\frac{dr_{K_i i}(t)}{dt} = \ldots$$

where:

r_K = output

NEW = grain d

$r_1 \ldots r_K$ = arr

K = order o

DEL - average

i = index o

The basic sur

in evaluating stra

areas for future r

facing a short ter

government component are for rural-to-urban transport of government grain and the arrival of foreign imports. Recall that this same modeling procedure is used to produce harvest rates in the production component. The input is a one-time pulse in the case of harvests.

$$\frac{dr_{1j}(t)}{dt} = \frac{K_i}{DEL_i} \left(NEW_i(t) - r_{1j}(t)\right) \tag{2.18a}$$

$$\frac{dr_{2i}(t)}{dt} = \frac{K_i}{DEL_i} \left(r_{ij}(t) - r_{2i}(t)\right) \tag{2.18b}$$

$$\vdots \qquad\qquad \vdots$$

$$\frac{dr_{K_i i}(t)}{dt} = \frac{K_i}{DEL_i} \left(r_{K_i-1,i}(t) - r_{K_i\, i}(t)\right) \tag{2.18c}$$

where:

r_K = output of delay = grain arrivals (MT/year)

NEW = grain dispatched (MT/year)

$r_1 \ldots r_K$ = array of intermediate rate variables of the delay

K = order of the delay (describes the distribution)

DEL - average transportation time (years)

i = index on variables.

Summary

The basic survival model described here was constructed as an aid in evaluating strategies for famine relief and identifying fertile areas for future research. The model describes a hypothetical country facing a short term food crisis and simulates the dynamic demographic, economic, producti

model is highly ag

country, but it sh

life operation. A

discussed in Chapt

tion system compon

economic, production, and decision-making processes over time. The model is highly aggregated and does not adequately detail a specific country, but it sheds light on important issues to be faced by any relife operation. Additions and modifications to the basic model are discussed in Chapter 3 where the model is augmented with an information system component.

MO

To allow evalu

performance of fami

basic survival mode

chapter describes a

component.

An approach to

a specific applicat

component to the ba

cific application,

ernment component

ing modeling links

and decision making

aggregation as the

on information qual

sampling frequency

details of surveil

avoided. The last

portant modeling p

It is importa

in the overall inf

CHAPTER III

MODELING AN INFORMATION SYSTEM

To allow evaluation of the effects of information quality on the performance of famine relief efforts, appropriate modifications of the basic survival model of the preceeding chapter are necessary. This chapter describes a general approach to modeling an information system component.

An approach to assessment of information systems is described and a specific application is considered with the addition of a sampling component to the basic model. Much of the material refers to this specific application, but the approach should be clear. The model's government component is organized for information system addition, providing modeling links among surveillance, data processing, communication, and decision making functions. To keep additions at the same level of aggregation as the basic model, a sampling component is devised based on information quality. The important concepts of measurement error, sampling frequency and processing delay are included while the complex details of surveillance technique, communication networks, etc., are avoided. The last section of the chapter covers several small but important modeling problems often met in simulation work.

Modeling and Evaluation

It is important to realize the context of a computer simulation in the overall information system for famine relief (see Figure 1.1).

The model is one
purpose is to pr
to be encountere
examines specifi
and very simplif
programs, and ou
data processing
tion network. T
variables can ne
tion system incl
relief work, tog
quality.

The system e
ographic, produc
system performan
tionships betwee
ity. Important
having most effe
fect), optimal l
straints, and th
structures.

Two performa
minimization of
both observed at
because they spe
volved. The mai
opposed to addit

The model is one of many tools to be used by the system planners. Its purpose is to provide insight into the processes and structure likely to be encountered during a food crisis. The basic model of Chapter II examines specific aspects of the affected people, the system managers and very simplified versions of transport and logistics, government programs, and outside aid. Our attention now turns to the surveillance, data processing and communication components; the heart of the information network. The problem becomes one of estimation, since many dynamic variables can never be known perfectly. The evaluation of an information system includes learning how precise the data must be for efficient relief work, together with the cost of obtaining the desired data quality.

The system evaluation is largely a sensitivity analysis. The demographic, production, and market components are fixed, objectives of system performance are defined, and observations are made of the relationships between system performance and changes in information quality. Important problems to solve include determination of data items having most effect on policy performance (and those having least effect), optimal levels of information quality with given cost constraints, and the interrelationships between data items and policy structures.

Two performance objectives are used in this study. These are minimization of total deaths and total accumulated nutritional debt, both observed at the end of one year (T=1.0). These goals are chosen because they specifically measure the well-being of the people involved. The main damage of a food crisis is to the population, as opposed to additional economic and facilities losses incurred by war or natural disast

the population to

how well prepared

Many other c

minimization of e

The goals used he

optimization stud

jective to two ar

many. It is assu

give needed gene

Second, each cou

the fact that bo

for judging fami

A third type

nutritional debt

functional relat

out considerable

examining the co

tional debt. An

ers. Since tota

per-capita consu

tritional debt.

crease in nutrit

level must be me

which time most

choosing one yea

or natural disasters. The time frame of one year is chosen to allow the population to move through one complete harvest cycle and to assess how well prepared the people are to face another possible crisis.

Many other objectives are possible: maximization of storage, minimization of economic loss, minimization of social disruption, etc. The goals used here are limited to two for several reasons. First, in optimization studies, the technique changes needed in going from one objective to two are generally more difficult than in going from two to many. It is assumed that several objectives may be used and two will give needed generality without introducing unneeded complications. Second, each country must choose its own performance objectives, and the fact that both deaths and nutritional level are standard measures for judging famine extent provides a general case (46).

A third type of generality achieved by choosing deaths and total nutritional debt as criteria is that they are inversely related. Any functional relationship between them is too complex to determine without considerable effort. The inverse relationship is easy to see by examining the combination of processes that lead to deaths and nutritional debt. An increase in the number of deaths means fewer consumers. Since total available foods is fixed, fewer people means higher per-capita consumption, causing higher nutritional level, or lower nutritional debt. Similarly, a decrease in deaths is followed by an increase in nutritional debt. Since this is a dynamic process, the debt level must be measured significantly after the initial harvest, by which time most deaths have occurred. (This is another reason for choosing one year as the measurement point.)

The single g

situation. Throu

very small death

population weak a

to provide genera

fects of famine o

Two benchmar

the information s

information stand

the best possible

specifically desi

involves price co

much use of addit

informational qua

specific famine r

The availability

ture as the clair

policies and impe

two boundaries.

The quality

meters: the stan

error is assumed

and the delay tim

for system manage

world activities,

the model. As ar

are transmitted t

The single goal of minimizing deaths can lead to a precarious situation. Through a similar chain of events as described above, a very small death rate will cause a large nutritional debt, leaving the population weak and vulnerable to disease. So two criteria are chosen to provide generality and to give a comprehensive measure of the effects of famine on the population.

Two benchmarks are easily identifiable to judge the performance of the information system. The worst possible case, from a quality-of-information standpoint, would be continuation of normal policy, and the best possible case would be the use of perfect information in specifically designed relief activities. Normal policy in the model involves price controls to determine food allocation, does not make much use of additional nutritional data, and will be little affected by informational quality. This "worst" case represents operation without specific famine relief information and will be the minimal cost system. The availability of perfect information is referred to in the literature as the clairvoyant case (22). System performance using relief policies and imperfect information should fall somewhere between the two boundaries.

The quality of a given data system is modeled here with four parameters: the standard deviation and bias of measurement error (the error is assumed to be normally distributed), the sampling frequency, and the delay time between measurement and availability of information for system managers. The parameters can be varied to account for real world activities, but the activities themselves are not included in the model. As an example, a decreased delay time is possible if data are transmitted by telephone rather than messenger. To account for

this change, the
the cause. Agair
ity. Specific co
cal methods will
try, and would or
of model developm
sub-systems as pa

The four cho
generality. The
data processing,
in an actual app
sate for long la
meter follows th
convenient base
surveillance cos
reporting observ
ganization, mach
used in studying
duced by the sta
sumed to be norm
sumed because th
private storage
through the erro
the central lim
average value a

this change, the delay parameter is decreased; no mention is made of the cause. Again, this approach is taken in the interests of generality. Specific communication devices, sampling techniques and statistical methods will differ in cost and applicability from country to country, and would only add complexity that is unnecessary at this stage of model development. Chapter V does probe into some of the specific sub-systems as part of cost analysis.

The four chosen parameters provide a great deal of flexibility and generality. The delay term represents the sum of all surveillance, data processing, and communication lags. To achieve a given delay time in an actual application, adjustment can be made in one area to compensate for long lags in another. The use of a sampling frequency parameter follows the real world data acquisition process and provides a convenient base for determining the amount of data generated and the surveillance costs. Bias is included to account for regular errors in reporting observations. Possible causes would be bureaucratic disorganization, machinery errors, or corruption. This parameter is not used in studying the current model. Random measurement error is produced by the standard deviation parameter; error distributions are assumed to be normal with mean equal to the true value. Normalcy is assumed because the variables estimated (accumulated nutritional debt, private storage, etc.) are averages derived from many samples. Althrough the error term of each individual sample may not be normal, the central limit theorem guarantees that the distribution of the average value approaches normalcy as the number of samples increases.

Orga

Policy stru
sired policies d
information helps
policies. In ger
and leads to more
the planning stag
be estimated valu
of probable varia
using a computer
streams are typic
two.

The modeling
and the productio
tions follow the
"true" variables.
for actual govern
man-made decision
Many simulation a
can assume that e
the error is smal
the difference be
ably the most imp

The organizat
events present in
cessing functions
As depicted in Fig

Organization of the Government Component

Policy structure and information gathering are intertwined; desired policies dictate the types of data needed, and the quality of the information helps determine the likelihood of success of implemented policies. In general, better data allows more knowledgable decisions and leads to more successful outcomes. It is important to realize in the planning stage that the only data available during the crisis will be estimated values of actual dynamic variables and *a priori* knowledge of probable variable movement. This is especially significant when using a computer simulation, because both the actual and estimated data streams are typically present. Care must be taken to differentiate the two.

The modeling of the rural and urban populations, the market sector and the production component is done using actual values. The calculations follow the natural relationships and clearly call for the use of "true" variables. The same is true of the bookkeeping equations needed for actual government storage and imports. But the introduction of man-made decisions requires a second stream of values, the estimated. Many simulation applications, such as queueing or inventory models, can assume that estimated and true values of information are equal, if the error is small or unimportant to the problem being considered. But the difference between in-hand data and real world conditions is probably the most important concept in information system evaluation.

The organization introduced here follows the logical sequence of events present in any information system. The inputs to the data processing functions are the true values of the variables to be estimated. As depicted in Figure 1.1, data are collected, processed, and

communicated. Al
calculations and
timated, stochas

Since the i
parameters, the
as one unit. It
sible for the in
described in the
pling frequency.
of the rest of t
quence.

The requir
computation, an
a sampling comp
other means. T
rates of change
gate statistic
cannot be comp
and a computed
of the calcula
in the decisio
food rates, be

A particu
example of the
information sy
sitions, sales
uses the exac

communicated. Along the way, measurement errors are introduced and calculations and transmission time cause natural delays. Lagged, estimated, stochastic variables are used in making decisions.

Since the information stream is being represented by data quality parameters, the surveillance and communications components are modeled as one unit. It is assumed that these are the functions most responsible for the introduction of errors and delay. The sampling component described in the next section provides for error, delay, and the sampling frequency. This forms the core of the modeling additions; much of the rest of the organization needed involves correct computation sequence.

The required order of calculation is simple: estimation, complex computation, and decision rule use. Variable estimates are made with a sampling component, an exponential delay (see Equation 3.1), or some other means. Then calculations can be made to determine target levels, rates of change, and aggregated statistics. An example of an aggregate statistic is the average available nutrition rate (ARNUT), which cannot be computed until estimates of imports, storage, population, and a computed figure for time of desired storage are known. The form of the calculation is given in Equation 2.12. ARNUT can now be used in the decision rules for determining allocation, sales, and emergency food rates, because it is an estimated variable.

A particular change of the basic model is mentioned here as an example of the need for consistent calculations when evaluating the information system component. The Equations 2.13-2.15 determine acquisitions, sales, and emergency food levels in the basic model. Each uses the exact population figure, a practice that is perfectly acceptable excep

the problem bein

has been added a

the new form.

Sa

A simple me

to a simulation.

approaching info

is to avoid the

munication metho

real delays, mea

The randomized e

Equation 3.1) a

of the calculat

at each time in

$EST_k(t) =$

where:

EST = esti

NEW = true

DEL = para

SD = erro

RR = uni

acceptable except when the precision of the inexact variable is part of the problem being studied. Thus, an estimate of each population class has been added and used in the revised model. See Equation 3.8 for the new form.

Sampling Component--SAMPL and VDTDLI

A simple method is needed to introduce data quality parameters into a simulation. Simplicity is desirable, since one of the reasons for approaching information system evaluation through the use of parameters is to avoid the detail of describing particular surveillance and communication methods. At the same time, the method must approximate the real delays, measurement error and sampling frequency in the system. The randomized exponential delay of the basic model (repeated here as Equation 3.1) accounts for delay and measurement error, but the form of the calculation assumes constant sampling; a new input is processed at each time increment of the model

$$EST_k(t) = EST_k(t-\Delta t) + \frac{\Delta t}{DEL_k} * ((1. + SD_k * RR) *NEW_k(t) - EST_k(t-\Delta t) \qquad (3.1)$$

where:

EST = estimated value of variable

NEW = true value of variable

DEL = parameter; average delay (years)

SD = error parameter

RR = uniform random variable $\left(\frac{1}{-2}, \frac{1}{2} \right)$

Δt = time

k = index

Certainly t

the information

but because of t

cost; more sampl

exponential dela

a sort of percen

systematic bias

The followi

generality then

the specified i

actual variable

distribution fu

ter as the mode

the sample serv

For the periods

done to attempt

scheme holds th

interval.

The detail

features are n

culation in th

contained in A

in more detail

Δt = time increment of discrete model (years)

k = index on variables.

Certainly the sampling frequency is an important characteristic of the information system, not only from the standpoint of data quality, but because of the direct relationship between sampling frequency and cost; more sampling implies higher costs. A further drawback of the exponential delay is that there is only one measurement error parameter, a sort of percentage standard deviation. A parameter representing systematic bias in the observations is also desirable.

The following routines are quite easily implemented and allow more generality then Equation 3.1. A sampling frequency is given and, at the specified intervals, random measurement error is introduced. The actual variable, plus or minus a bias term, serves as the mean of the distribution function. The sampled value is then stored in the computer as the model advances through a given delay period, after which the sample serves as the estimated value to be used in decision rules. For the periods between sampling points, some form of filtering can be done to attempt to follow the actual variable. The simplest filtering scheme holds the sampled value as a constant estimate throughout the interval.

The details of sampling component (SAMPL and VDTDLI) modeling features are now presented. The description follows the order of calculation in the routines. A complete listing of the FORTRAN code is contained in Appendix B. These routines are described and validated in more detail in Chapter VII.

The discrete

$\underline{X}$ into a specifie

simple counter (N

occurs. The cour

checked against

of desired varia

that SAMPT can b

$NSAMP_k$ = SA

where:

NSAMP = nun

SAMPT = sar

DT = sir

k = in

The measur

lection, is sim

dom standard er

depending on th

estimation comp

second method

dard deviation

$EST_k(ST)$

$EST_k(ST)$

where:

EST = es

VAL = tr

The discrete model translates the sampling interval parameter of $\underline{X}$ into a specified number of simulation cycles, using Equation 3.2. A simple counter (NCNT) is set to zero each time the sampling procedure occurs. The counter NCNT is incremented by one each cycle DT and is checked against the sampling interval size NSAMP. Thus, measurement of desired variables takes place only at specified intervals. Note that SAMPT can be dynamic.

$$NSAMP_k = SAMPT_k \;/\; DT + .5 \qquad (3.2)$$

where:

NSAMP = number of simulation cycles in sampling interval

SAMPT = sampling interval (years)

DT = simulation cycle increment (years)

k = index on variables.

The measurement of a desired variable, corresponding to data collection, is simulated in SAMPL with the introduction of bias and random standard error parameters. Two estimation equations are possible, depending on the characteristics of the true variable. One method of estimation computes an error term proportional to the true value. The second method generates a normally distributed error with fixed standard deviation. The equations used are 3.3 and 3.4 respectively.

$$EST_k(ST) = VAL_k(ST) * (1. + SD_k * Y) * BIAS_k \qquad (3.3)$$

$$EST_k(ST) = VAL_k(ST) + SD_k * Y * BIAS_k \qquad (3.4)$$

where:

EST = estimated value of variable

VAL = true value of variable

BIAS = meas

ST = samp

Y = star

k = inde

Straightfor

estimates in bo

estimate varian

$VAL_k^2 * SD_k^2$ whil

call E(Y) = 0.0

tributed errors

is in the stand

true value; the

The form o

since the stand

But this method

considerably or

tion 3.3 depend

that measuremen

The choice

series data fo

considerably b

possibly for s

reason for usi

conceivable th

Per-capit

3.4 since the

BIAS = measurement bias

ST = sampling time

Y = standard normal random variable

k = index on variables.

Straightforward calculations show that the expected value of the estimates in both equations is the true value plus the bias term. The estimate variances differ: Equation 3.3 produces a variance equal to $VAL_k^2 * SD_k^2$ while the variance of EST from Equation 3.4 is SD_k^2. (Recall $E(Y) = 0.0$, $var(Y) = 1.$) Both calculations produce normally distributed errors, since Y is a normal random variable. The difference is in the standard deviation of the error: one is proportional to the true value; the other is fixed.

The form of Equation 3.3 is preferable for discussion purposes since the standard deviation can be described as X% of the true value. But this method becomes an inaccurate model if the true values vary considerably or approach zero. Since the size of the error in Equation 3.3 depends on the size of the variable, the implication would be that measurement techniques get better as the variable decreases.

The choice of error estimators is based on examination of time series data for true variable values. Private storage levels vary considerably but the low values stay comfortably away from zero except possibly for short periods just before harvest time. An additional reason for using Equation 3.3 for storage levels is that it would be conceivable that with less grain to measure, error would be reduced.

Per-capita nutritional debt estimation must be done with Equation 3.4 since the true values are small (on the order of 10^{-2}MT/person) and can be either

are also small (ap

only during the mo

Subroutine SA

The estimates are

tine, VDTDLI. Th

boxcar routines (

changes in the de

to telephone serv

current study, bu

problems encounte

A boxcar del

string of railroa

the train empties

with the latest

each car moves f

cess. The equat

OUT = CA

CAR_{i-1} = CA

CAR_N = IN

where:

OUT = outp

CAR_i = ith

IN = inp

i = ind

N = num

and can be either positive or negative. Per-capita consumption rates are also small (approximately $2*10^{-1}$MT/person-year) but approach zero only during the most dire emergencies.

Subroutine SAMPL produces estimates values for sampled variables. The estimates are then used as inputs to a discrete, variable delay routine, VDTDLI. The form of the delay follows that of familiar discrete boxcar routines (35). VDTDLI has the added capability of handling changes in the delay rate, as might occur with a change from messenger to telephone service. The variable delay capability is not used in the current study, but is described here as an indication of the particular problems encountered with information flow.

A boxcar delay routine is so named because it operates much like a string of railroad cars on a circular track. The car at the front of the train empties its load at the designated output point. A new car with the latest supplies (or information) joins the train's tail. And each car moves forward one position. Equations 3.5 describe this process. The equations must be solved in the order presented.

$$OUT = CAR_1 \quad (3.5a)$$

$$CAR_{i-1} = CAR_i, \text{ for } i=2,3,\ldots,N \quad (3.5b)$$

$$CAR_N = IN \quad (3.5c)$$

where:

OUT = output of routine

CAR_i = ith car in the array

IN = input to routine

i = index on cars

N = number of cars.

The delay pa

number of array p

tion is simply do

N_k = DELAY$_k$/

where:

N = size

DELAY = dela

DT = simu

k = inde

Notes that

the array, or tr

an input and out

Changes in

tion from the ta

An increased del

od. Equations 3

Equation 3.5c.

CAR_j = IN ,

Where

j = inde

NNEW = new

N = old

CAR = arr

A decrease

information unc

The delay parameter of information quality is related to N, the number of array positions, by the simulation increment DT. The calculation is simply done in Equation 3.6.

$$N_k = DELAY_k/DT + .5 \qquad (3.6)$$

where:

N = size of delay array

DELAY = delay parameter in $\underline{X}$ (years)

DT = simulation increment (years)

k = index on variables.

Notes that the relationships of Equations 3.5 and 3.6 require that the array, or train, be updated each simulation cycle. There must be an input and output each cycle DT.

Changes in delay time always cause addition or deletion of information from the tail of the train; the newest data values are affected. An increased delay causes the newest data to be held for the extra period. Equations 3.5a and 3.5b are retained, but Equation 3.7 replaces Equation 3.5c.

$$CAR_j = IN \text{ , for } j=N,N+1,N+2,\ldots,NNEW \qquad (3.7)$$

where

j = index on new cars in array

NNEW = new size of delay array

N = old size of delay array

CAR = array element.

A decreased delay does not cause loss of data. Rather, the newer information under the old delay scheme is superseded by new data from the new scheme.

cannot force the

only modification

the new, shorter

ion in modeling i

The output c

used in decision

an input and prov

model. SAMPL ca

val, so addition

is to retain a s

throughout the s

Chapter 2) will

offer three oppo

dures. Filterin

sults of previou

cess. Polynomia

VDTDLI between s

more closely tha

variable observe

estimation prob

The problem

modeling patter

Each varia

tinct informati

the new scheme. This implies that implementation of the new methods cannot force the old information through the system any faster. The only modification to Equations 3.5 is that N is recalculated to fit the new, shorter delay. Note that conservation of flow is not a criterion in modeling information transfer.

The output of VDTDLI is a lagged, randomly measured estimate to be used in decision rules of the government component. The routine needs an input and provides an output at each time interval of the discrete model. SAMPL calculates a new estimate only once each sampling interval, so additional inputs to VDTDLI are necessary. The simplest scheme is to retain a sampled value from SAMPL as a constant input to VDTDLI throughout the sampling interval. This common zero-order hold (11, Chapter 2) will be the base method used in this study. SAMPL and VDTDLI offer three opportunities for further estimation or filtering procedures. Filtering techniques can be used in SAMPL to include the results of previous measurements of the variable in the estimation process. Polynomial smoothing or similar methods can predict inputs to VDTDLI between sampling points which, hopefully, will track true values more closely than the zero-order hold. And a priori knowledge of the variable observed can lead to modified estimation procedures. This estimation problem is discussed in more detail in Chapter 6.

Model Variable Choice

The problem of the particular variables to be estimated with the modeling pattern of SAMPLE and VDTDLI is now examined.

Each variable included has the potential of generating four distinct information quality parameters. Thus, too many variables could result in complex

sensitivity and o

with less than th

balk at more than

age requirements

with the number c

only the estimate

tion system will

computer outputs

sults by the glu

We turn to

ber of variables

timated is dicta

categories based

famine. Many it

Population, gove

already monitore

system for famin

ables not yet s

storage are dec

this second cat

called for by t

ables to estima

scheme would be

---

*As an exa
lear, quadratic
parameters and

result in complexities too great for standard analysis. Most of the sensitivity and optimization literature on computer simulations deals with less than three or four parameters, and the more powerful routines balk at more than fifteen parameters (60). Computation costs and storage requirements for optimization work seem to increase factorially with the number of parameters.* An additional consideration is that only the estimated values directly linked to a famine relief information system will be examined in studying data precision. Generation of computer outputs with too many data items can obscure important results by the glut of numbers produced.

We turn to real world conditions for a means of limiting the number of variables and parameters. The total number of values to be estimated is dictated by policy structure. The variables fall into two categories based on need for additional sampling specifically during a famine. Many items are included in existing information systems. Population, government storage levels, crop and harvest conditions are already monitored in almost all countries. Design of an information system for famine relief will be especially concerned with the variables not yet sampled often enough. Nutritional debt and private storage are decision variables from the current model that fall into this second category. These are the generally unknown data items called for by the policy design. Another criteria for choosing variables to estimate in a sampling component (the alternative estimation scheme would be an exponential or similar delay) is the rate at which

---

*As an example, a standard least squares regression including linear, quadratic and interaction terms for n variables requires $1+2n+\binom{n}{2}$ parameters and the inversion of a square matrix of that size.

the variable vari

normally tend to

levels. In gener

difficult. More f

niques may not ca

An alternati

parameters to be

estimations and s

mation system eva

point made in the

world conditions

allowing concent

Per-capita

variable, to be

resulting form o

Equation 3.8. S

model have simil

rural consumptio

values are used

GAQU(t) =

where:

GAQU = g

ERSTOR = e

GRSTRD = g

the variable varies with time. Population levels and crop conditions normally tend to change slowly, relative to consumption and nutritional levels. In general, more rapid changes make the estimation process more difficult. More frequent sampling is required, and simple modeling techniques may not capture real world behavior.

An alternative approach for limiting the number of variables and parameters to be analyzed would be to use the sampling component for all estimations and select only the most sensitive variables for the information system evaluation. This is certainly a valid process. The point made in the previous paragraph is that examination of the real world conditions and objectives can eliminate much needless analysis, allowing concentration on the items perceived to be most crucial.

Per-capita consumption has been added as a decision rule control variable, to be used in much the same manner as nutritional debt. The resulting form of the government acquisitions decision rule is given in Equation 3.8. Sales and emergency food rate equations of the basic model have similar alterations. Note that acquisitions increase when rural consumption is greater than average urban consumption. Estimated values are used throughout.

$$\begin{aligned} GAQU(t) = {} & CG30 * \max(ERSTOR(t) - GRSTRD(t)) \\ & + CG36 * (AEUNDP(t) - ERNTDP(t)) * EPR(t) \\ & + CG35 * (EPCONR(t) - AEUPCN(t)) * EPR(t) \end{aligned} \tag{3.8}$$

where:

GAQU = government acquisitions from rural sector (MT/year)

ERSTOR = estimated rural private storage (MT)

GRSTRD = government desired rural private storage (MT)

AEUNDP = av
(M

ERNTDP = es

EPCONR = es

AEUPCN = av
pe

EPR = es

CG30, CG36.

Per-capita
of nutritional
decision rules
sumption provid
differences in
on relative nut
an overshoot, a
sumption level
recently receiv
allocation to t

The addit
where policy s
the change. T
of the decisio
have been reco
Nations, which
tional surveil
elements are
levels and dis
by real world

AEUNDP = average estimated urban per-capita nutritional debt (MT/person)

ERNTDP = estimated rural per-capita nutritional debt (MT/person)

EPCONR = estimated rural per-capita consumption (MT/person-year)

AEUPCN = average estimated urban per-capita consumption (MT/person-year)

EPR = estimated rural population (persons)

CG30, CG36, CG35 = control parameters.

Per-capita consumption forms part of the rate of change process of nutritional debt, providing a sort of derivative control for the decision rules (11, Chapter 2). In practical terms, knowledge of consumption provides a tool to help avoid serious overcompensation for differences in nutritional level. That is, when allocation is based on relative nutritional debts, sustained allocation priority can cause an overshoot, a reversal of roles between the two classes. The consumption level takes account of the differences in amounts of food recently received by the two classes and proportionately decreases the allocation to the class that is eating more.

The addition of consumption level as a control variable is a case where policy structure and real world conditions coincide to dictate the change. The derivative control was needed to increase the power of the decision rules. Consumption rates as well as nutritional level have been recognized as important pieces of information by the United Nations, which is encouraging all nations to adopt some form of nutritional surveillance (25). It should be noted that many other data elements are needed for comprehensive famine relief, especially water levels and disease incidence. Consideration of these items is prompted by real world conditions, but they fall outside the scope of the

preliminary moc
food as a means
distribution ar
nutritional moc

Three var
sampling compo
variable, per-
ates four esti
data quality e
exists. Fortu
time streams o
The time requi
assumed to be
one delay para
data are assum
so one samplin
for each of th
of the sampli
common sampli
surveys are t

There ar
of rural vers
last until th
classes desi
parameters mu
classes can

preliminary model used here. The current focus is on allocation of food as a means of equalizing nutritional levels. Eventually water distribution and health care may be added to the policy structure and nutritional modeling.

Three variable types have been chosen as inputs to the current sampling component: nutritional debt, private storage, and the new variable, per-capita consumption. Each variable type actually generates four estimates, one for each population group. Given the four data quality elements, a total of forty-eight possible parameters exists. Fortunately, similarities in the processes modeled and the time streams of the variables allow considerable numerical duplication. The time requirements of surveillance and transmission processes are assumed to be similar for each variable type, allowing the use of just one delay parameter. The sampling error of nutritional and consumption data are assumed not to vary significantly across population classes, so one sampling frequency, standard deviation and bias are postulated for each of these variable types. The assumption relies on the ability of the sampling teams to measure different groups equally well. The common sampling frequency corresponds to a real world situation where surveys are taken of all population groups simutaneously.

There are substantial differences in the size and rate of change of rural versus urban private storage. Recall that rural storage must last until the next harvest (nine months at the longest) while urban classes desire stores that last one to three weeks. Thus four separate parameters must be used for rural private storage, although the urban classes can share four parameters.

These econom
thirteen: one de
deviations, and b
are not used in t
the causes of bia
area for further
lative ease of ar
The nine rem
inputs that will
mization work. T
assigning it a ve
quality paramete

Addi

The three p
allow evaluation
tions are presen
for this dissert
nificance, they
the changes are
the next chapter
edge of the type
simulation of a
An assumpt
outside aid bey
of this model i
resources. Thi

These economies in parameter use have reduced the total needed to thirteen: one delay and four each of sampling frequencies, standard deviations, and biases. It was mentioned earlier that bias parameters are not used in this study. The main reason for this deletion is that the causes of bias will be specific in each country and are left as an area for further research. A secondary but important reason is the relative ease of analyzing nine parameters instead of thirteen.

The nine remaining data precision elements form a set of variable inputs that will be used extensively for sensitivity analysis and optimization work. The importance of this parameter set is underlined by assigning it a vector representation, $\underline{X}$, the vector of information quality parameters.

Additional Assumptions and Modifications

The three previous sections cover the major additions needed to allow evaluation of the information system. Several further modifications are presented here that apply specifically to the modeling effort for this dissertation. Although the particulars are not of general significance, they are discussed for two reasons. The assumptions behind the changes are noted to provide background for results described in the next chapter. And it is hoped that the reader will gain some knowledge of the types of problems and subtleties inherent in a computer simulation of a famine.

An assumption made throughout the study is that there will be no outside aid beyond the purchased government imports. A main purpose of this model is to examine efficient means of allocating available resources. This allocation problem exists even with substantial international a

need for effici

that includes re

no international

aid is available

crisis conditio

easily adapted t

of the simulatio

There is no

food distributio

has almost enoug

feeding would in

However, any rel

particularly the

tion as the urba

zation purposes,

and emergency pr

tinction of rura

nots, although t

Due to init

parameter sets c

to zero. This t

tive nutritional

causes the consu

fairly quick equ

as planned for b

sales is highly

international aid; the aid changes the level of crisis, but not the need for efficient policies and a good information system. Planning that includes reliance on outside help may be disastrous if there are no international reserves at the time of the famine. In the event that aid is available, there will be a time interval between recognition of crisis conditions and food arrival. So the approach used here could be easily adapted to include outside food aid by limiting the time horizon of the simulation and setting a level of expected aid.

There is no provision in current policy structure for emergency food distribution to the rural class. The defined "rural" population has almost enough food initially. So the addition of rural emergency feeding would involve buying food and giving it back, a wasted effort. However, any relief program will involve aid to those in rural raeas, particularly the landless poor who would be in roughly the same situation as the urban poor classes of this model. Indeed, for conceptualization purposes, the rural poor can be combined with the urban poor, and emergency programs for both groups labeled EMFDG. The class distinction of rural and urban might better be labeled the haves and have-nots, although the physical location may be an important distinction.

Due to initial values assigned the urban classes, certain control parameter sets can force the level of government desired sales (GSLSDU) to zero. This typically occurs when the wealthy urban class has negative nutritional debt; they are overfed. The withholding of sales causes the consumption level of the rich to plummet, and there is fairly quick equalization of nutritional debt across the urban classes, as planned for by the policy structure. However, the event of zero sales is highly unrealistic. There is some food available, especially

at the onset of
a cutoff of the
is contrary to
practical reaso
mainly by the r
of available fo
may be infeasib
economic reason
level of sales,
(ARNUT). The m

Another si
occur in the re
incorrect way
to force a non
flow problems
tion used here
output is term

The three
gency food han
storage (RSTOR
tivity cutoffs
cision variab
able. When s
to zero. Unl
of delays; an
shortage hits
variables sin

at the onset of the crisis (when GSLSDU is most likely to hit zero) and a cutoff of the supply to one particular class even for a short period is contrary to the humanitarian purposes of famine relief. A more practical reason for non-zero sales is the fact that purchases are made mainly by the rich, and the rich will probably get at least their share of available food, assuming that power goes with wealth. In fact, it may be infeasible to limit sales at all to the rich for political or economic reasons. Thus, the assumption is made that there is a minimal level of sales, proportional to the average available nutrition rate (ARNUT). The minimum proportion is set at seventy-five percent.

Another situation that occurs in the modeling world but cannot occur in the real world is having a storage level dip below zero. One incorrect way to combat negative storage is to use a maximum function to force a non-negative value. But this can lead to conservation of flow problems if output rates remain larger than input rates. The solution used here follows the actions that would occur in a real case; output is terminated if storage drops too low.

The three government activities of acquisitions, sales, and emergency food handouts could cause direct depletions of rural private storage (RSTOR) or government urban storage (GSU). Two levels of activity cutoffs are used, one large storage level for the unlagged decision variables and a smaller value for the lagged, implemented variable. When storage drops below the designated setting, the rate is set to zero. Unlagged cutoffs are set higher in keeping with the nature of delays; anticipation of a shortage should occur before the actual shortage hits. Quite small storage levels are used to cut the lagged variables since they are slow to rebuild, especially with the use of exponential del

model stability.

Two uses o

rural-to-urban

Since the delay

transient respo

lay (two months

tained by using

logical that im

non-zero. One-

both transport

are set equal,

mediate rates a

case where inpu

conserve materi

The final

rather than mo

volving random

which are base

for obtaining

parameter set

different rand

distribution o

calculated fr

age requireme

variance recu

stored values

exponential delays. Lagged variable cutoff could cause a shock to model stability.

Two uses of distributed delays are mentioned in Chapter II, for rural-to-urban transport of government grain and for import shipments. Since the delays are initialized with zero values in the basic model, a transient response occurs, lasting approximately the length of the delay (two months in the case of imports). Smaller transients can be obtained by using non-zero initial values for initial rates, and it is logical that import and government shipment rates would normally be non-zero. One-half the maximum was chosen as the starting value for both transport rates. The inputs and outputs of the distributed delays are set equal, making intermediate rate initialization easy; all intermediate rates are identical to the common input-output rate. In the case where input does not equal output initially, care must be taken to conserve material flow in the delay (40, Chapter 10).

The final modification to be discussed has to do with computer use rather than modeling. The stochastic results of simulation runs involving random variables call for statistical evaluations, many of which are based on sample means and variance. The standard technique for obtaining the desired statistics is Monte Carlo simulation. A parameter set is fixed and several separate model runs are made using different random values (29). Each run produces one sample from the distribution of a given variable. The desired statistics are then calculated from the samples, using well known formulas. Computer storage requirements are reduced considerably by calculating the mean and variance recursively, according to Equations 3.9. Note that only two stored values, $\overline{X}_n$ and S_n, are required for each variable. Another advantage of th

available after

ing hypothesis

$\overline{X}_1 = x_1$, S

$\overline{X}_n = \frac{1}{n}((n-$

$S_n = \frac{n-2}{n-1}$ *

where:

n = numbe

x_n = nth s

$\overline{X}_n$ = sampl

S_n = sampl

Several pu

modifications.

scope of the mo

needed to incre

And recursive e

tion aid.

This chapt

tion systems us

economic, and p

objectives are

its effect on s

advantage of the recursive calculation is that current statistics are available after each run, providing a convenient structure for conducting hypothesis testing with a minimum number of computer runs.

$$\overline{X}_1 = x_1,\ S_1 = 0 \qquad (3.9a)$$

$$\overline{X}_n = \frac{1}{n}((n-1)\overline{X}_{n-1} + x_n)\ ;\ n \leq 2 \qquad (3.9b)$$

$$S_n = \frac{n-2}{n-1} * S_{n-1} + \frac{1}{n}(\overline{X}_{n-1} - x_n)^2\ ;\ n \leq 2 \qquad (3.9c)$$

where:

n = number of samples

x_n = nth sample

$\overline{X}_n$ = sample mean of n samples

S_n = sample variance of n samples.

Several purposes can be distinguished in the above assumptions and modifications. Types of aid present are noted to limit and define the scope of the model. Initial value and situational modeling changes are needed to increase the correspondence between real world and model. And recursive equations for sample mean and variance provide a calculation aid.

Summary

This chapter presents a general approach to evaluation of information systems using computer simulation techniques. The demographic, economic, and production components of the computer model are fixed, objectives are defined, and information precision is varied to determine its effect on system performance.

The decis

world behavior

calculation se

A samplin

described. Th

four data qual

veillance and

The probl

sensitivity an

is discussed.

effort are pre

problems and s

With the

for verificati

ination of sim

several unexpe

requiring subs

modeling struc

the use of the

larities.

The decision making component must be well-organized to match real world behavior. Particular attention is paid to maintaining correct calculation sequence and using only estimated values in decision rules.

A sampling component, consisting of two FORTRAN subroutines, is described. The routines model variable estimation through the use of four data quality parameters, avoiding the details of particular surveillance and communication system alternatives.

The problem of choosing the variables and parameters for use in sensitivity and optimization work is examined, and a general principle is discussed. Several of the assumptions used in the current modeling effort are presented to provide needed background and a feel for the problems and subtleties likely to be encountered.

With the addition of a sampling procedure, the model is now ready for verification and validation, using sensitivity analysis and examination of simulation outputs. The model described here produced several unexpected and, in some cases, undesirable numerical results, requiring substantial changes in the policy rules and the nutritional modeling structure. Chapter 4 describes the problems, the changes, and the use of the information system component in detecting the irregularities.

Wi

consist

with an

tion sy

several

set by

meters.

tency a

prices,

tual da

behavio

change

Th

and ser

expecte

lead to

shorter

System

set for

sultin

CHAPTER IV

THE INFORMATION SYSTEM MODEL AS AN AID IN POLICY DEVELOPMENT AND MODEL VERIFICATION

With the completion of Chapters II and III, the simulation model consists of the basic demographic, economic, and government sections with an added sampling component. Before evaluations of the information system can take place, the model needs to be "fine tuned" and several verification procedures conducted. Parameter limits can be set by observing allowable output changes due to changed input parameters. Verification involves, among other things, checking for consistency and reasonableness. Simulation output values for population size, prices, etc., should be sensible and, if available, should track actual data. The model should be consistent with assumed and observed behavior; a known input change should either produce an expected output change or provide clues to the incorrectness of the expectation.

The information component can be a useful aid in the verification and sensitivity testing process. A basic assumption is made about the expected effects of changing data quality: better information should lead to better system performance. "Better" information refers to shorter delays and sampling intervals and smaller measurement errors. System performance is defined by the objectives (minimize deaths, etc.) set forth by decision makers. So, by observing performance changes resulting from variation of the information parameter vector $\underline{X}$, the soundness

adequacy c

Each

tions and

mulation a

An evoluti

expected r

apparent a

in the las

The i

mation sys

policy str

felt that

ations wou

Hence, th

mathemati

a cost co

Mini

subj

where:

F

G

X

soundness of the problem formulation and policy structure and modeling adequacy can be tested.

Each of the next three sections of this chapter describes corrections and additions to the basic model and to the original problem formulation as required by violations of information quality assumptions. An evolutionary process unfolds as the model behaves more and more like expected real world activities. Several general conclusions become apparent about efficient famine relief. These conclusions are presented in the last section.

A Changed Problem Formulation

The intended research path of this study was to examine the information system effects apart from all other considerations, particularly policy structure. Because of the general "approach" nature here, it was felt that specific policy structures, crisis levels, and cultural variations would be better studied at the time of actual application. Hence, the desire for an efficient and economic information system was mathematically formulated as a multiresponse minimization problem with a cost constraint, as in Equation 4.1.

$$\text{Minimize } \underline{F}(\underline{X}) \qquad (4.1)$$

$$\text{subject to } \underline{G}(\underline{X}) \leq \underline{C}_1$$

$$\text{and } \underline{D}_1 \leq \underline{X} \leq \underline{D}_2$$

where:

$\underline{F}$ = system performance vector (total deaths, total nutritional debt)

$\underline{G}$ = cost function vector

$\underline{X}$ = information quality vector (delays, sampling intervals, measurement errors)

$\underline{C}_1$ = r

$\underline{D}_1$,$\underline{D}_2$ = c

This form
questions, the
validity of co
can be done wi
two or three d
effect observe
stricted to th

However,
ent formulatio
is sensitive t
be included wi
case that, as
sented in the

Before co
tion quality,
policy struct
directions on
should follow
to equalize nu
consists of al
ings. The pol
rules which de
As an example
affecting gove

$\underline{C}_1$ = resource constraint vector

$\underline{D}_1, \underline{D}_2$ = constraints on information quality.

This formulation has several advantages. By avoiding all policy questions, the information system can be examined directly. To test validity of conclusions acorss policy structure changes, optimizations can be done with distinct government decision components. Similarly, two or three different crisis levels can be simulated and data decision effect observed. The scope of each optimization problem is nicely restricted to the parameters of the $\underline{X}$ vector.

However, there is no *a priori* evidence for accepting this convenient formulation. If the optimal performance level of a policy parameter is sensitive to changes in data precision, then that parameter should be included with $\underline{X}$ in optimization studies. It could easily be the case that, as information quality improves, stricter controls (represented in the model by large parameters) can be instituted.

Before continuing the discussion of policy sensitivity to information quality, distinctions should be drawn among relief strategies, policy structure, and policy parameters. The structure consists of directions on *what* to do, the decision rules themselves. Structure should follow from the overall strategy. In this study the strategy is to equalize nutritional debt across the population; the policy structure consists of allocation through acquisitions, sales, and emergency feedings. The policy parameters are the specific variables of the decision rules which determine the timing and rates of the various activities. As an example, the Equation 3.8 is a defined part of policy structure affecting government acquisitions (GAQU). The parameters CG36, CG35, and CG30 determ

hidden paramete

activities by s

refer to policy

the vector $\underline{P}$.

Policy par

formance. A si

bility. Distir

be sufficient).

tor. The tests

elaborate exper

of the sensitiv

fixed $\underline{X}$. Note

for a given $\underline{X}$,

system will va

optimal policy

sensitivity ca

in $\underline{X}$. For inf

is by far more

variation is p

used. But if

Numerous

fixed $\underline{X}$ values

as "clairvoyan

---

*Optimali
jective functi
Pareto optimal

and CG30 determine the rate at which acquisitions are made. A somewhat hidden parameter (CG21) determines the start and end of acquisition activities by signaling a state of emergency. "Policy" will henceforth refer to policy structure. The policy parameter set will be noted by the vector $\underline{P}$.

Policy parameters $\underline{P}$ may have an effect on information system performance. A simple set of sensivitity tests can check for this possibility. Distinct values for $\underline{X}$ are chosen (two or three vectors should be sufficient). Sensitivity tests on $\underline{P}$ are made for each fixed $\underline{X}$ vector. The tests can be one parameter variation or can involve more elaborate experimental design and optimization techniques. The intent of the sensitivity analysis is to move toward an "optimal"* $\underline{P}$ at each fixed $\underline{X}$. Note that two types of sensitivity will be present. First, for a given $\underline{X}$, policy parameter changes will affect performance. The system will vary in sensitivity to the individual $\underline{P}$ parameters. Once optimal policy parameters are chosen for each $\underline{X}$, the second type of sensitivity can be examined, the sensitivity of $\underline{P}$ values to changes in $\underline{X}$. For information system evaluation, the second type of sensitivity is by far more important. If only the performance sensitivity to $\underline{P}$ variation is present, the assumed formulation of Equation 4.1 can be used. But if $\underline{P}$ varies with $\underline{X}$, a new problem statement is needed.

Numerous sensitivity simulation runs were made at three different fixed $\underline{X}$ values. The information vectors chosen are listed in Table 4.1 as "clairvoyant," "good," and "poor" data quality. The clairvoyant

---

*Optimality is complicated by the multiresponse nature of the objective function. $\underline{P}$ may consist of many vectors, each producing a pareto optimal response.

Table 4

Preli

X Parameters
Delay (weeks)
Nutrition Sampling
Consumpti Sampling
Private S Sampling
Standard Devi
Bias

Table 4.1. Information Quality Parameters Used for Preliminary Policy Parameter Sensitivity Tests

	Data Quality Sets		
X Parameters	Clairvoyant	Good	Poor
Delay (weeks)	0.2	1.0	2.0
Nutritional Debt Sampling Interval (weeks)	0.1	1.0	4.0
Consumption Sampling Interval (weeks)	0.1	1.0	4.0
Private Storage Sampling Interval (weeks)	0.1	2.5	6.0
Standard Deviation	0.0	0.0	0.0
Bias	0.0	0.0	0.0

vector assumes

the so-called

data precision

exercise. The

mal $\underline{P}$ paramete

costs can be

tic portions

intervals for

the discrete

Fourteen

involved iden

variations in

vector. Tota

with total nu

The resu

fourteen para

and six were

results. Th

related in t

tentative fo

crude and pr

model used f

this chapter

$\underline{X}$ performanc

tained in Ch

meters do in

vector assumes near-perfect knowledge of available information, while the so-called good and poor vectors represent successive degradation in data precision. Note that measurement error terms were not used in this exercise. The purpose of the sensitivity tests is to determine if optimal P parameters are sensitive to X changes. A savings in computation costs can be realized if P is shown to be sensitive to the non-stochastic portions of X. It should also be noted that the delay and sampling intervals for the clairvoyant case are the smallest values possible with the discrete model and sampling component constraints.

Fourteen P parameters were chosen for sensitivity tests. The tests involved identifying a base vector, observing results of ten percent variations in each parameter singly, then moving toward a better base vector. Total death count was used as the main criterion of choice, with total nutritional debt secondary.

The results of the crude optimization process showed that of the fourteen parameters, three were definitely sensitive to X variation and six were not. The remaining five parameters produced inconclusive results. Thus, a tentative conclusion was drawn that P and X are interrelated in their effects on system performance. The conclusions are tentative for two reasons. First, the sensitivity tests described are crude and produced, at best, likely local pareto optima. Second, the model used for the tests was not completely validated; the rest of this chapter contains numerous modifications that could affect P versus X performance. A more thorough study of the sensitivity problem is contained in Chapter VIII where the conclusion is drawn that policy parameters do interact with information quality parameters in influencing system performa

will also be gi

A new prob

the effect of $\underline{X}$

ating informati

policy paramete

Minimize $\underline{F}$

subject to

ar

where:

$\underline{F}$ = s

$\underline{G}$ = c

$\underline{X}$ = i

$\underline{P}$ = s

$\underline{C}$ = c

$\underline{D}_1, \underline{D}_2$ = c

$\underline{E}_1, \underline{E}_2$ = c

Note that

retically, cha

cause substan

the constrain

costs.

The cost

sons. First,

system performance. A more complete description of sensitivity testing will also be given at that time.

A new problem formulation is proposed in Equation 4.2. Because the effect of $\underline{X}$ on $\underline{P}$ is the only sensitivity type of interest in evaluating information system work, the $\underline{P}$ in Equation 4.2 consists only of policy parameters whose optimal values change with $\underline{X}$.

$$\text{Minimize } \underline{F}(\underline{X},\underline{P}) \qquad (4.2)$$
$$\text{subject to } \underline{G}(\underline{X}) \leq \underline{C}$$
$$\text{and } \underline{D}_1 \leq \underline{X} \leq \underline{D}_2$$
$$\underline{E}_1 \leq \underline{P} \leq \underline{E}_2$$

where:

$\underline{F}$ = system performance vector

$\underline{G}$ = cost function vector

$\underline{X}$ = information quality vector

$\underline{P}$ = sensitive policy parameter vector

$\underline{C}$ = constraint vector

$\underline{D}_1,\underline{D}_2$ = constraints on information quality

$\underline{E}_1,\underline{E}_2$ = constraints on policy parameters.

Note that the cost constraint remains a function of $\underline{X}$ only. Theoretically, changes in $\underline{P}$ will affect program administration and could cause substantial cost and manpower variation. This would imply that the constraining function should become $\underline{G}(\underline{X},\underline{P})$ to account for policy costs.

The cost function is left as $\underline{G}(\underline{X})$ for several very practical reasons. First, the policy costs will greatly exceed information system costs. Addin

in informatio

team in charg

only with the

of programs,

affect the su

are not inclu

sideration is

sis, a factor

tic nature.

Possibly

policy costs

tor. Dependin

be in critica

allocation of

formation sys

straints in t

will restrict

and constructi

Information Qu

The resul

the basic info

sents graphs o

vectors. The

with clairvoya

better than po

costs. Adding policy and information expenses would obscure changes in information cost during optimization work. Secondly, a planning team in charge of information system design will likely be concerned only with their own budget and other resource constraints. The costs of programs, although important in the overall relief system, will not affect the subsystem planners. Similarly, transportation system costs are not included in the information system optimization. A third consideration is that policy parameters are affected by the level of crisis, a factor that cannot be explicitly planned for due to its stochastic nature.

Possibly the most important reason for not adding information and policy costs is that monetary restrictions may not be the limiting factor. Depending on the stricken area, equipment, personnel, or time may be in critically short supply. The major decisions would then involve allocation of trained people, trucks, and radios to programs, the information system, or transportation work. The objective of the constraints in the problem formulation should be to identify factors which will restrict optimal system performance. Chapter V examines the form and construction of $\underline{G}$.

Information Quality Validation

The results of preliminary sensitivity work were disconcerting: the basic information quality assumption was violated. Figure 4.1 presents graphs of total deaths through time for the three sets of $\underline{X}$ and $\underline{P}$ vectors. The curves increase as expected through the first half year, with clairvoyant data working better than good data, which are, in turn, better than poor data. The leveling off of deaths after the first

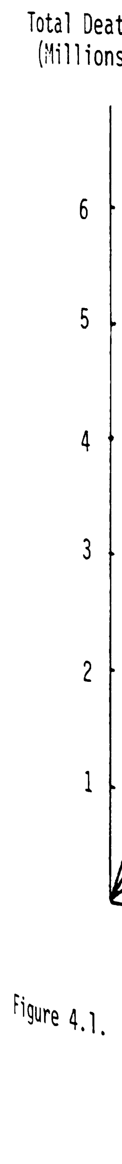


Figure 4.1.

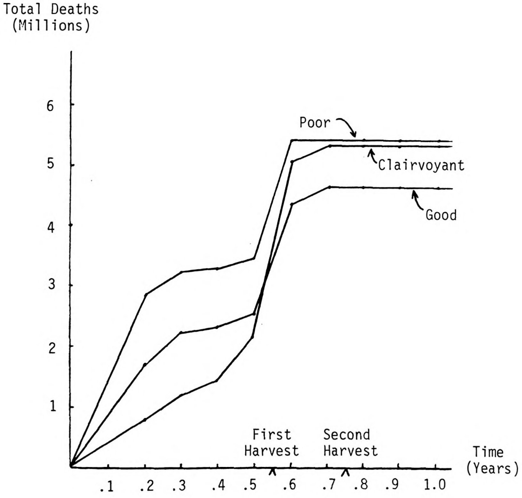


Figure 4.1. Total Deaths for Different Information Quality Sets.

harvest indica
combined to cr
some situation
T = (.5 years,
rapidly, shoot
ing the total

Several p
culated P val
cies, the poli
natural phenom
tion. Further
bination of a
curves in Fig
formation has
plained.

The prob
information h
likely cause
lar equations
is known; it
population gr
and lower tot
model are kno
should indica

harvest indicates that the reduced population and good harvests have combined to create a more stable nutritional climate. But a troublesome situation occurs just before the first harvest, in the period T = (.5 years, .6 years). Deaths in the clairvoyant case mount most rapidly, shooting above results from the "good" data and almost reaching the total from the "poor" data.

Several possible causes exist for the observed behavior. The calculated P values may not be optimal, the model may have inconsistencies, the policies may not be correctly formulated, or there may be a natural phenomenon occurring which is obscured by non-perfect information. Further work described in the next sections reveals that a combination of all the above factors is responsible for the shape of the curves in Figure 4.1. The key fact uncovered here is that better information has produced worse results; this inconsistency must be explained.

Policy Structure Additions

The problem exhibited in Figure 4.1 is quite fundamental: better information has produced worse results. The steps in discovering a likely cause for this vexation involve moving back through the particular equations that lead to the problem. The overall relief strategy is known; it is desired to spread nutritional debt evenly across all population groups. This should equalize death rates for all classes and lower total deaths. Simulated time series for all variables in the model are known. Comparison of desired results and simulated variables should indicate a direction for problem solution.

Figure 4.

classes for th

are such that

rural poution

deaths almost

outperforms th

much closer fo

after the harv

and urban conc

case, the urba

is narrowed or

available food

Relating

be seen that

exclusively by

much of the in

habits of rura

increase near

the harvest s

plies at that

The dist

harsh reality

consumption m

population ex

the harvest.

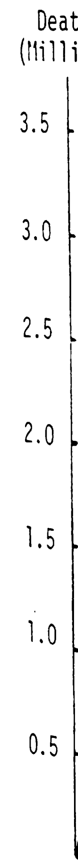
the early por

"crunch," pre

Figure 4.2 depicts the breakdown of total deaths by urban and rural classes for the clairvoyant and poor data sets. Because initial values are such that the total urban population is approximately equal to the rural popution, the desired policy result is to have rural and urban deaths almost equal. By this criterion alone, the clairvoyant data set outperforms the poor quality data. Rural and urban death totals are much closer for the better data case, particularly in the stable region after the harvests ($T > .7$). But there is a large gap between rural and urban conditions during the early crisis. Even for the best data case, the urban deaths lead rurals by as much as 1.2 million. The gap is narrowed only at the height of the crisis when presumably no one has available food.

Relating Figure 4.2 to the total death curves of Figure 4.1, it can be seen that the large initial jump in total deaths is caused almost exclusively by urban suffering, while the rural population accounts for much of the increase immediately preceding harvest time. The different habits of rural and urban classes account for the larger rural death increase near the harvest. Rural consumption is tied more directly to the harvest start, so the rurals are more likely to exhaust their supplies at that time.

The distinct shapes of the urban and rural death curves suggest a harsh reality. With a limited amount of food available, more early consumption means much worse conditions at the crisis peak. The rural population exhausts its supplies early and suffers greatly just before the harvest. The urban group, on the other hand, eats too little in the early portion of the famine but is then not as affected by the "crunch," presumably because there are fewer people to feed. The



Fi

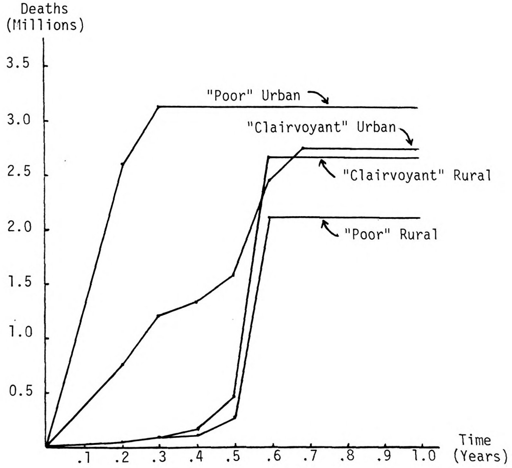


Figure 4.2. Deaths by Rural and Urban Classes for Different Information Quality Sets.

advantage of s

especially in

port requireme

more is availa

stark: short-

Increase Early

Increasin

should serve a

based on its r

should eventua

nation of the

parameter is p

government urt

that with gove

are protected

increasing the

hood of early

Unfortuna

Initial condi

is negative;

of acquisitio

chases are ma

A policy

adequately co

ence acquisit

policy modifi

advantage of slowly increasing nutritional debt can be clearly seen, especially in relation to the rural class. By consuming less, life support requirements are less, to a point. Thus, less food is needed and more is available at the worst times. The conclusions is chillingly stark: short-term gains can lead to long-term disaster.

Increase Early Acquisitions

Increasing acquisitions from the rural sector early in the crisis should serve a dual purpose. The rural class should reduce consumption based on its reassessment of storage levels. And the urban classes should eventually benefit from the increased government stocks. Examination of the policies shows a possible immediate remedy. A cutoff parameter is part of the acquisitions policy to stop purchases when government urban storage is too high. The reasoning for the cutoff is that with government storage above a certain level, the urban classes are protected and acquisitions would unfairly hurt the rural class. By increasing the cutoff value or eliminating it altogether, the likelihood of early acquisitions increases.

Unfortunately, a second hindrance to early acquisitions exists. Initial conditions are such that average urban nutritional debt (AEUNDP) is negative; the urban rich are overfed. This reduces the desirability of acquisitions according to Equation 3.8, so that little or no purchases are made.

A policy addition is needed. The former policies are unable to adequately control results since parameter changes alone cannot influence acquisitions. Several loose guidelines can be set for allowable policy modifications. A well-defined policy objective is needed that is in line wit

explicit timin

especially for

policy's worth

Here, the

the rural sect

control becaus

rural personal

an emergency h

average nutrit

since the regu

reasoning lead

tion 4.3.

If a) a

and b) A

then GAQU

where:

GAQU =

ERSTOR =

GRSTRD =

AEUNDP =

CG45 =

Addition

quisitions rat

rule is smoot

Rural deaths

is in line with the overall relief strategy. Parameters should provide explicit timing and rate controls. And simplicity is highly desirable, especially for assessment of policy effectiveness. The final test of a policy's worth is its ability to positively influence system performance.

Here, the desired policy must increase government purchases from the rural sector early in the harvest. Nutritional debt is not a good control because the urban average figure is initially negative. But rural personal storage is still a possible control. And the fact that an emergency has been declared can serve as a starting signal. Urban average nutritional debt greater than zero can serve as an ending signal since the regular policy of Equation 3.8 can then take over. The above reasoning leads to a simple proposed early acquisitions policy, Equation 4.3.

If a) an emergency has been declared

and b) $AEUNDP \leq 0.0$,

then $$GAQU(t) = \max(CG45*(ERSTOR(t) - GRSTRD(t)),0.0) \qquad (4.3)$$

where:

GAQU = government acquisitions (MT/year)

ERSTOR = estimated rural private storage (MT)

GRSTRD = government desired rural private storage (MT)

AEUNDP = average urban nutritional debt (MT/person-year)

CG45 = rate parameter ($year^{-1}$).

Addition of Equation 4.3 to the model does increase the early acquisitions rate, and the transition to the normal purchase decision rule is smooth. But the effects on death rates are not as desired. Rural deaths do increase slightly at the beginning of the emergency.

However, the t

ban population

acquisitions b

These new

large increase

rural class ex

are a cause, a

for transporta

help the urban

tor. The poss

storage as the

that governmen

Reduce Harvest

Thus, the

the harvest.

maximum functi

tion policy (E

A test of this

cally. Unfort

but to harm th

without the ru

acquisitions f

The secon

because common

model performa

tions could ch

when rural con

However, the toll at the crisis peak is higher than ever. And the urban population shows no improvement until several weeks after the early acquisitions begin.

These new results lead to an examination of the causes of the large increase in rural deaths just before harvest time. Clearly, the rural class exhausts its food stocks. Perhaps, excessive acquisitions are a cause, along with overconsumption. It appears that the lag times for transportation and policy implementation restrict the ability to help the urban classes through government purchases from the rural sector. The possibility arises that grain is piling up in government storage as the rural class starves, since a time series analysis showed that government rural storage is consistently greater than desired.

Reduce Harvest Acquisitions

Thus, the next policy to address is reduction of acquisitions near the harvest. Two solutions suggest themselves. First, dropping the maximum function on the rural private storage control of the acquisition policy (Equation 3.8) should decrease purchases when stocks drop. A test of this modification showed that acquisitions do fall dramatically. Unfortunately, the main effect is not to help the rural class, but to harm the urban classes, because government stocks are exhausted without the rural grain. Evidently, there are causes beyond excessive acquisitions for the large rural death toll.

The second method for reducing government purchases is implemented because common sense dictates its inclusion. The effect on current model performance is negligible, but a different set of initial conditions could change its importance. The policy is to stop acquisitions when rural consumption falls below the minimum life-sustaining level.

At this point,

broken down an

expended to tr

people is wast

If EPCONR

where:

GAQU =

EPCONR =

UK5 =

Alleviate Tran

Transport

effectiveness

ies analysis

a thorough st

designing eff

policy modifi

of informatio

They were unco

total.

The satu

link causes a

ment rural st

tion that is

that of a gra

ships into do

hicles (truck

At this point, the reasoning behind nutritional debt equalization has broken down and disaster is inevitable without outside aid. The energy expended to transfer food from rural starving people to urban starving people is wasted. Thus, the inclusion of decision rule Equation 4.4.

$$\text{If } EPCONR(t) \leq UK5, \text{ then } GAQU(t) = 0.0 \quad (4.4)$$

where:

GAQU = government acquisitions (MT/year)

EPCONR = estimated rural consumption (MT/person-year)

UK5 = minimum life sustaining nutrition (MT/person-year).

Alleviate Transport Bottleneck

Transportation lags were mentioned earlier as a hindrance to policy effectiveness. Several implications have been derived from a time series analysis of the transport process in the current model. Certainly, a thorough study of transport and distribution systems is needed in designing efficient relief efforts. The following observations and policy modifications are included as examples of the interrelationships of information systems, transportation systems, and policy structure. They were uncovered as possible contributions to the huge rural death total.

The saturation of the rural-to-urban government transportation link causes a serious bottleneck. This occurs when inputs to government rural storage exceed outputs, causing stocks to mount in a location that is not immediately accessible. The problem is similar to that of a grain-handling seaport where the grain is offloaded from ships into dockside storage silos and then onto appropriate land vehicles (truck or train). Results of previous simulation work on seaport operat

put rate from

the expected i

adequate trans

is essential f

Two simpl

increase outpu

for in the fol

government sto

low. The "tri

levels at whic

port delays. T

a slight modifi

is simply obtai

(CG25) whose va

If (GSU(t)

then GSRU(

If (GSR(t)

then (GAQU(

where:

GSU = go

GSR = go

GSUD = go

GSRD = go

GSRUMX = ma

GAQU = go

seaport operations indicate that to avoid excessive buildups, the output rate from silo to land transport must be considerably larger than the expected input rate of grain in ships (30). The implication is that adequate transportation (ship to storage or between storage locations) is essential for the operation of any allocation policies.

Two simple ideas exist for alleviating the transport saturation: increase outputs or decrease inputs. Both possibilities are arranged for in the following policy additions. Increased outputs from rural government storage (GSR) are desired when urban storage (GSU) falls too low. The "trigger" level of GSU must be considerably larger than the levels at which emergency programs are stopped, to account for transport delays. The parameter GSUD serves as the trigger in Equation 4.5, a slight modification of Equation 2.10. The increased transport rate is simply obtained by multiplying the normal rate (CG1) by a factor (CG25) whose value is greater than one.

If (GSU(t) $\leq$ GSUD),

then GSRU(t) = min(GSRUMX, max(CG1*CG25*(GSR(t)-GSRD),0.0) (4.5)

If (GSR(t) $\leq$ GSRD),

then (GAQU(t) $\leq$ GSRUMX - EIMP(t) (4.6)

where:

GSU = government urban storage (MT)

GSR = government rural storage (MT)

GSUD = government desired urban storage (MT)

GSRD = government desired rural storage (MT)

GSRUMX = maximum transport rate (MT/year)

GAQU = government acquisitions (MT/year)

EIMP =

CG1 =

CG25 =

Equation
current model
sitions so th
(GSRUMX). In
was tried in
GAQU, causing
in Equation 4

Four pol
of model outp
better inform
testing. Un
data quality
led to only a
worsened the
sumption tim
the informat
causes discu

The sam
duces worse
modified to
ward the inc
produced the

EIMP = estimated imports (MT/year)

CG1 = normal transport parameter ($year^{-1}$)

CG25 = crisis transport increase parameter (dimensionless).

Equation 4.6 represents a limit placed on inputs to GSR. In the current model all increases in GSR are due to either imports or acquisitions so that inputs to GSR cannot exceed maximum possible outputs (GSRUMX). In an alternative formulation, current transport rate (GSRU) was tried in place of GSRUMX. This placed too great a restriction on GAQU, causing urban class suffering. The GSR restriction is included in Equation 4.6 to allow rural storage to increase it if falls too low.

Four policy additions have been made based on time series analysis of model outputs. The investigation was suggested by the fact that better information was producing worse results in initial sensitivity testing. Unfortunately, the policy additions have not eliminated the data quality inconsistency. Recall that increased early acquisitions led to only a small early increase in the rural death rate and greatly worsened the death toll at the "crunch." Analysis of per-capita consumption time series in the next section reveals a modeling cause for the information system trouble, in addition to the policy and natural causes discussed already.

Modeling Changes

The sampling component has revealed that better information produces worse results using the basic model. Policy structure has been modified to provide additional control over the processes leading toward the inconsistencies in total death figures. The policies have not produced the desired changes; especially disappointing is the lack of

results from s
the puzzle is
rate, per-capi
rural per-capi
policies from
effect of the

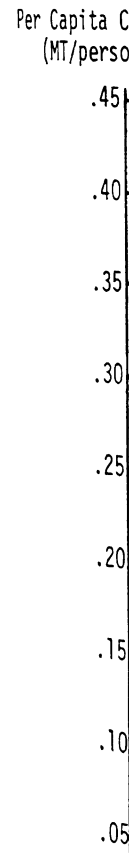
Two parts
ral population
acquisitions i
the people are
sistently overc
ity is the osci
peak is explain
following deep
pecially since
question. Thes

Undesirabl
period of time
measuring relie
time and the pr
tion work, poor
meter search is
rural per-capita
government acqui
modeling leading

results from substantial early acquisitions. The next step in solving the puzzle is an examination of the variable responsible for the death rate, per-capita consumption. Figure 4.3 contains time series plots of rural per-capita consumption both before and after the addition of policies from the previous section. By comparing the two curves, the effect of the new decision rules can be seen.

Two parts of the curves in Figure 4.3 are curious. First, the rural population does not appreciably change its consumption habits when acquisitions increase at the beginning of the crisis. It appears that the people are not adequately planning for the future since they consistently overconsume during these early stages. The second peculiarity is the oscillatory behavior during the harvests. The consumption peak is explainable as the result of the incoming harvest. But the following deep decline in eating does not match expected activity, especially since personal storage levels are high during the period in question. These two behaviors indicate a possible modeling problem.

Undesirable consequences abound if the model is incorrect. The period of time around the start of the first harvest is crucial for measuring relief effort performance. The crisis hits a peak at that time and the probability of disaster is at its greatest. In optimization work, poor modeling could lead to distorted results if the parameter search is trapped by a model inconsistency. The fact that the rural per-capital consumption curve does not respond to persistent government acquisitions could cause rejection of a wise policy, if the modeling leading to such results is wrong.



Per Capita C
(MT/perso
.45
.40
.35
.30
.25
.20
.15
.10
.05

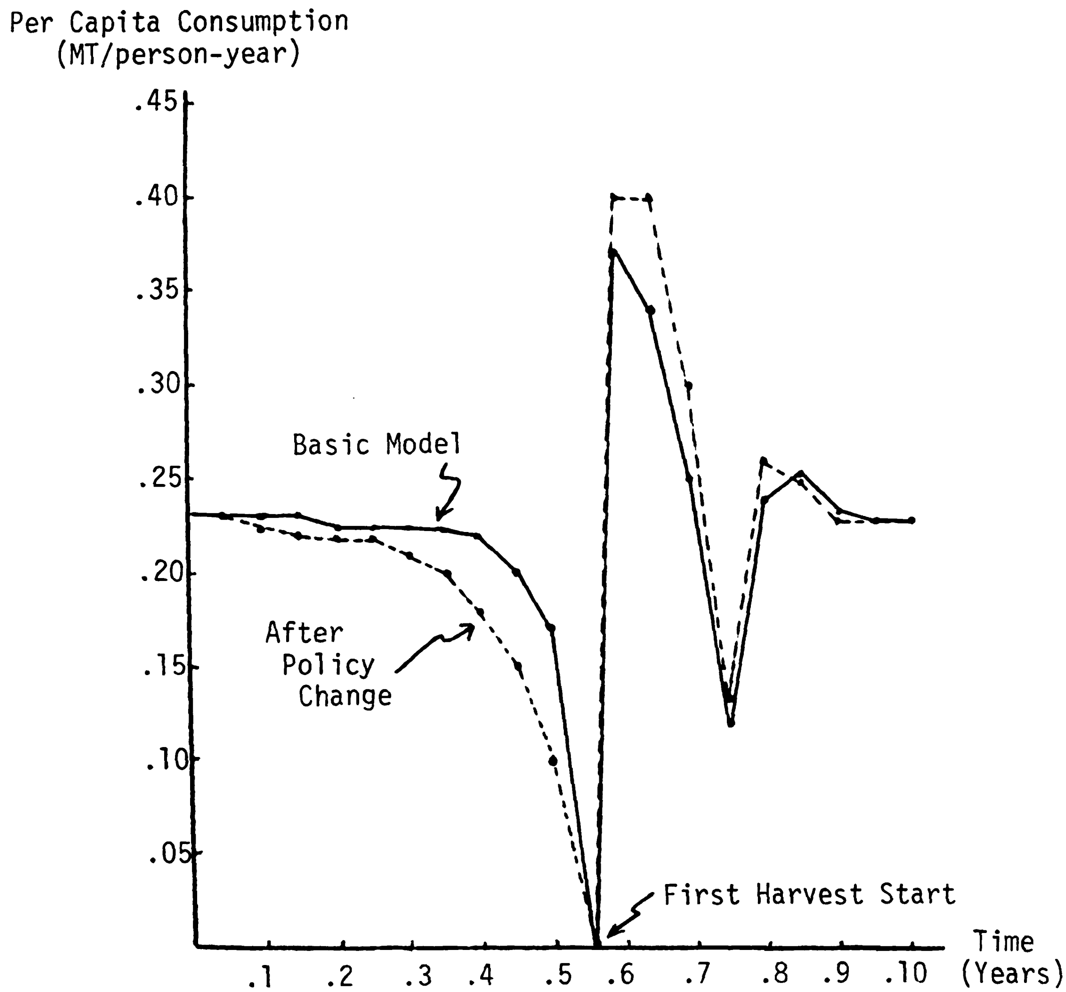


Figure 4.3. Rural Per-Capita Consumption
Before and After Policy Changes.

Principles fo

A few wo

the current m

tions. While

sented in Cha

principal mea

volves testin

havior (29).

empirical, du

study actual

famine) to g

rejection of

sistencies t

to affect.

Mass an

model varia

tions, these

several vari

1. Doe
pre

2. Doe
the

3. Doe
of

An example o

reduction in

the first an

cussed below

Principles for Change

A few words are needed here on procedures for determining whether the current model is accurate and whether to accept proposed corrections. While a more complete discussion of model validation is presented in Chapter VII, the verification method is mentioned here as a principal means of determining model corrections. Verification involves testing whether proposed equations match expected real world behavior (29). In the current case, expected behavior is reasoned, not empirical, due to a lack of data. This, of course, implies a need to study actual behavior (in this case, consumption habits preceding a famine) to ground the model in the real world. An obvious reason for rejection of a particular model occurs when there are persistent inconsistencies that parameters and applicable policy structure are unable to affect.

Mass and Singe give three criteria for determining whether one model variable is dependent on another (44). With slight modifications, these criteria can be applied to a modeling change involving several variables:

1. Does the modeling change lead to desirable changes in predicted numerical values of the system?

2. Does the modeling change lead to a desirable change in the system behavior mode?

3. Does the modeling change lead to a desirable changed view of preferable policies?

An example of the second criterion in the present problem would be a reduction in consumption oscillations during harvest time. Examples of the first and third criteria come to light as modeling changes are discussed below.

Rural Consump

Calculat

in Equations

of Equation 4

presents curr

expected stor

last. Thus, w

the harvest w

form of Equat

crease with t

of desired co

normal requi

Note that co

The intent o

senses an ap

XFR1(t)

FR1(t)

PCONSR(

where:

XFR1

FR1

F2

RSTOR

PR

EMFSU

Rural Consumption

Calculated rural consumption habits of the basic model are given in Equations 4.7, 4.8, and 4.9. The numerator on the right hand side of Equation 4.7 is actual private storage, RSTOR. The denominator represents current desired storage. It is computed as the product of the expected storage depletion rate and the time over which stocks must last. Thus, when XFR1 is less than one, storage will be exhausted before the harvest without consumption cutbacks or outside aid. The functional form of Equation 4.8 is given in Figure 2.2a, where FR1 is seen to increase with the ratio XFR1. Per-capita consumption is an FR1 fraction of desired consumption. Equation 4.9 computes desired nutrition as the normal requirement (RNUTPN) plus a recovery portion of nutritional debt. Note that consumption cannot go higher than four-tenths MT/person-year. The intent of these equations is to describe a rural population that senses an approaching shortage and reduces consumption accordingly.

$$XFR1(t) = RSTOR(t)/((RNUTPR(t)*PR(t) + EMFSU(t))*(TTSH(t) + SF)) \quad (4.7)$$

$$FR1(t) = F2(FR1(t)) \quad (4.8)$$

$$PCONSR(t) = \min(.4, (RNUTPN + RK6*RNUTDP(t))*FR1) \quad (4.9)$$

where:

XFR1 = ratio of current to desired rural private storage (dimensionless)

FR1 = rural food availability factor (dimensionless)

F2 = consumption habit function (depicted in Figure 2.2a)

RSTOR = rural private storage (MT)

PR = rural population (persons)

EMFSU = emergency food to urban relatives (MT/year)

RNUTPR =

RNUTPN =

RNUTDP =

PCONSR =

TTSH =

SF =

RK6 =

Examinat

cularities of

clue to the c

tion F2 in Fi

early acquisi

The cul

variable TTSH

harvest star

creases inst

real world s

want to have

end! The co

time of harv

vagaries of

more and mor

factor, whic

decrease wit

A new

Curve (a) o

RNUTPR = current nutritional requirements (MT/person-year)

RNUTPN = normal nutritional requirements (MT/person-year)

RNUTDP = rural nutritional debt (MT/person)

PCONSR = rural per-capita consumption (MT/person-year)

TTSH = time until start of next harvest (year)

SF = harvest time safety factor (year)

RK6 = recovery rate parameter ($year^{-1}$).

Examination of Equations 4.7-4.9 shows possible causes for the peculiarities of Figure 4.3. The denominator of Equation 4.7 provides a clue to the oscillatory behavior near the harvests. The shape of function F2 in Figure 2.2a suggests the non-repsonsiveness of rurals to early acquisitions.

The culprit in Equation 4.7 is the time of desired storage. The variable TTSH is computed as the difference between the time of the next harvest start and current time. Thus, TTSH is discontinuous; it increases instantaneously at the two harvest starts (T=.55, T=.75). If real world storage desires matched this variable, the rural class would want to have more grain stored at the beginning of a harvest than at the end! The constant safety factor SF also produces inconsistencies. The time of harvest is only approximately known early in the year, due to vagaries of weather. But as the harvest approaches, the farmer knows more and more precisely when crops will be ready. Thus, the safety factor, which represents a safeguard in case of a late harvest, should decrease with TTSH.

A new functional form for time of desired storage is pictured in Curve (a) of Figure 4.4. It is based on certain assumptions concerning

Tim
(Yea
.8
.7
.6
.5
.4
.3
.2
.1

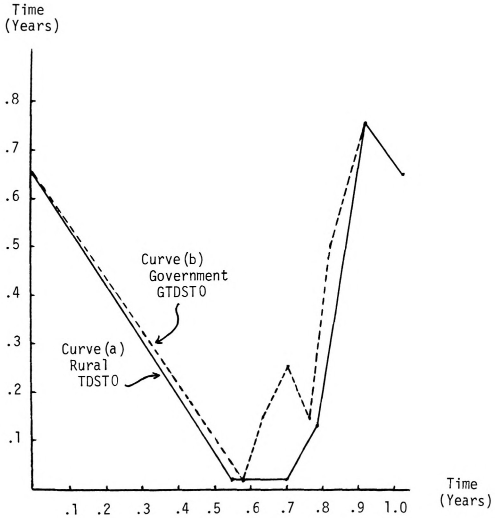


Figure 4.4. Rural and Government Desired Times of Storage.

a rural indiv

We expressly

the harvest.

sired storage

harvest and b

incorporates

harvest time.

The June

months. The

thought is g

and-a-half l

sold. After

as this crop

Curve (

function bas

curve is det

Randomized h

tions by the

inclusion in

The lac

function F2

fraction sta

Thus, the re

tightening.

is available

model descri

a rural individual's assessment of his/her needs and harvest timing. We expressly assume that people forward plan and space out food until the harvest. The expected time until harvest forms the base for desired storage time in the long period between the end of the second harvest and beginning of the first. A linear equation is given which incorporates a decreasing safety factor. The major changes occur at harvest time.

The June crop brings the first new supplies in at least eight months. The crisis is over, assuming that harvests are good. Little thought is given to storage buildup until near the end of the month-and-a-half long harvest period. Then grain is gradually stored or sold. After the start of the second harvest, storage begins in earnest, as this crop must last for another eight month period.

Curve (a) of Figure 4.4 represents a continuous, approximated function based on the assumed conditions of the basic model. The new curve is deterministic because the harvest times of the model are. Randomized harvest times would call for estimation of the crop conditions by the rurals. Such estimation is considered too detailed for inclusion in the current study.

The lack of rural response to early acquisitions is related to function F2 in Equation 4.8 and Figure 2.2a. The normal consumption fraction stays much too high, especially for XFR1 values above one-half. Thus, the result of early acquisitons is not to produce desired belt-tightening. Instead, rural stocks are exhausted more quickly and less is available at the crunch. (See Figure 4.3). Apparently, the basic model describes a population not well prepared for meeting a crisis.

It is po

eliminating f

Because of th

greater than

mendous over

the distinct

conservation

for acquired

Equation 4.9

consumption

tion for the

for good tim

Equations 4.

XFR1(t)

FR1(t)

PCONSR

Where:

TDSTO =

FR1

XFR1

All ot

The us

4.12 shoul

showed a te

ments) was

It is porposed to relate XFR1 directly to desired consumption, eliminating function F2. There is a drawback to this scheme, however. Because of the new desired storage time function, XFR1 often is much greater than one. Using the ratio indiscriminately could lead to tremendous overconsumption. This problem can be avoided by considering the distinct consumption desires in times of abundance versus times of conservation. When food is plentiful, the individual wants to make up for acquired nutritional debt, similar to the desired consumption of Equation 4.9. But during crisis times, sensible planning limits the consumption base to required nutrition. XFR1 is the availability fraction for the lean times, while one (1.0) must be the maximum fraction for good times. The new rural consumption modeling is summarized in Equations 4.10, 4.11, and 4.12.

$$XFR1(t) = RSTOR(t)/((RNUTPR(t)*PR(t) + EMFSU(t))* TDSTO(t)) \quad (4.10)$$

$$FR1(t) = \min(XFR1, 1.0) \quad (4.11)$$

$$PCONSR(t) = \min(.4, RNUTPN*XFR1(t), (RNUTPR(t)*RK6*RNUTDP(t))*FR1) \quad (4.12)$$

where:

TDSTO = time of rural desired private storage (year)

FR1 = food availability factor in good times

XFR1 = food availability factor in lean times

All other variables as in Equations 4.7-4.9.

The uses of RNUTPN and RNUTPR for desired consumption in Equation 4.12 should be noted. Model testing with various variable combinations showed a tendency toward underconsumption when RNUTPR (current requirements) was used for lean time desires. Similarly, overconsumption exists when R

results are n

are mentioned

Figure 4

above model c

of Figure 4.3

sumed. The p

sumably due t

tually impro

tightening o

al modeling

significant

ing fact to

tion again f

the hypothet

importance c

creased.

Urban Class

As men

marked impr

fitted mini

similar cha

revealed ar

recall from

tity of foo

rely on fr

exists when RNUTPN (normal requirement) is used in good times. These results are not highly significant in overall system performance, but are mentioned as possible further research areas.

Figure 4.5 presents the rural consumption curve resulting from the above model changes. Note that the harvest time oscillatory behavior of Figure 4.3 is reduced, leaving only the peak as first crops are consumed. The plunge before the harvest has also been eliminated, presumably due to more careful rationing. In fact, rural conditions actually improve just before the crisis hits. This suggests further tightening of acquisition controls. And, in fact, without the additional modeling changes described next, the urban classes suffer much more significant losses than the rurals. There is one additional interesting fact to be derived from Figure 4.5. Note that per-capita consumption again falls below RNUTPN after the harvests. This indicates that the hypothetical country of the model is chronically food-deficit; the importance of total nutritional debt as a performance objective is increased.

Urban Class Consumption

As mentioned above, changed rural consumption modeling produced marked improvement in the rural death toll, but the urban classes benefitted minimally. Perhaps the urban consumption equations require similar changes. Time series analysis of average urban consumption revealed an oscillatory behavior similar to that of Figure 4.3. But recall from Chapter II that urban consumption is based more on the quantity of food available than on the desired storage time. Urban classes rely on frequent purchases (or handouts) to replenish their supplies.

Per Capita
(MT/pers

.40

.35

.30

.25

.20

.15

.10

.05

Figu

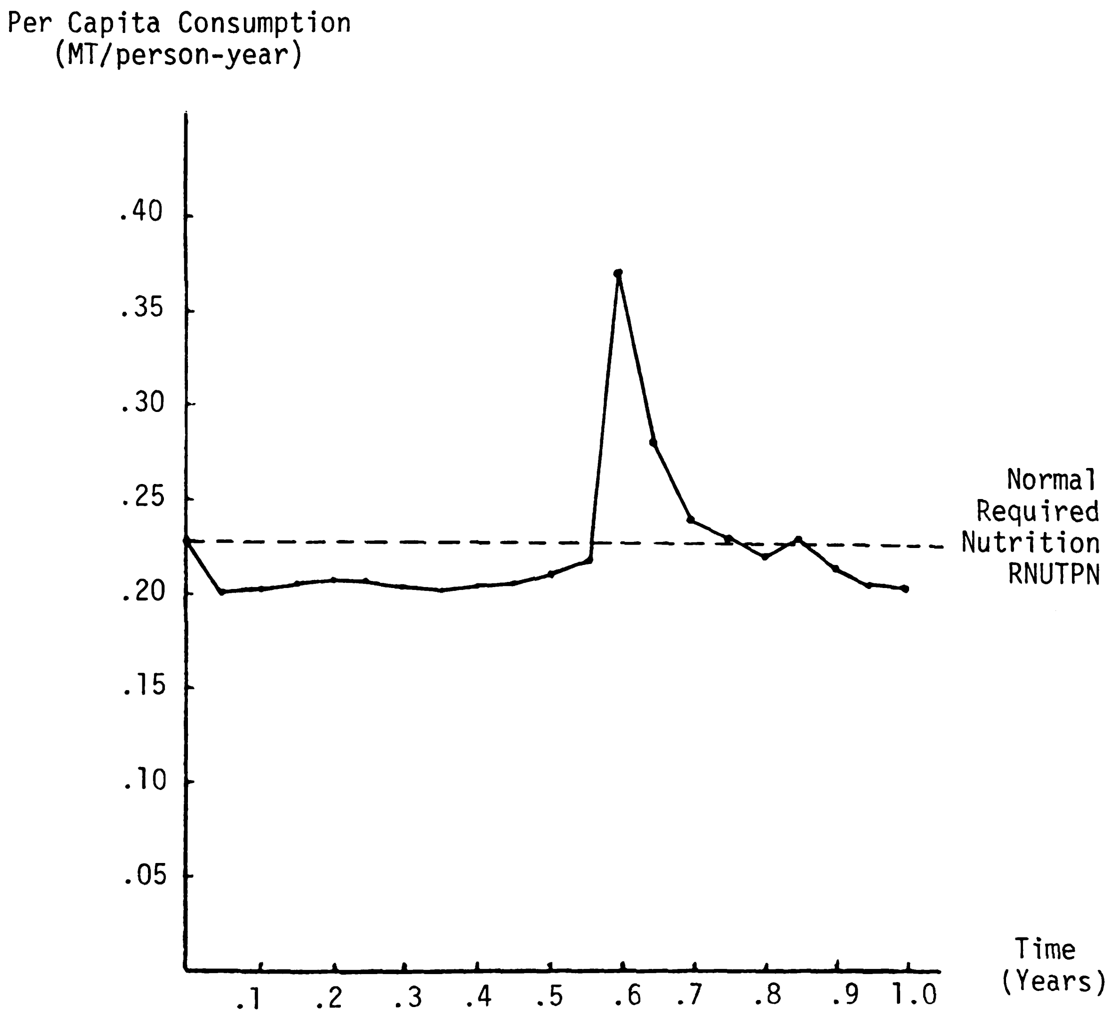


Figure 4.5. Rural Consumption After Modeling Changes.

The possibil

timal use of

would be tha

quantities.

when storage

tion curves

Urban c

cies. The s

is. The urb

during the c

on average a

tion 2.12.

changed form

replaces (T

the same osc

tion exhibi

been include

or decrease

mally, CG81

ditions or

Several tes

ARNUT(

where:

CG81

ARNUT

RNUTPN

The possibility exists that urban groups in the model do not make optimal use of available food at the peak of the crisis. The reason would be that the FU1 curve of Figure 2.2b goes to zero with storage quantities. But a modeling change to insure "hand-to-mouth" feeding when storage hits a given low point did not significantly alter consumption curves or system performance.

Urban consumption modeling is not the cause of urban inconsistencies. The same storage time calculation that plagued rural consumption is. The urban classes depend on government sales and feeding programs during the crisis. The decision rules for these actions depend heavily on average available per-capita nutrition (ARNUT), calculated in Equation 2.12. The new proposed form is given here as Equation 4.13. The changed form has a limit on the maximum value of ARNUT, and GTDSTO(t) replaces (TTSH(t) + SF). The discontinuous TTSH and constant SF caused the same oscillatory behavior in ARNUT and urban per-capital consumption exhibited by rural consumption. A control parameter, CG81, has been included in this equation to allow exploration of slight increases or decreases in the government calculations of usable nutrients. Normally, CG81 would equal one. But it may be that continual slight additions or cutbacks in ARNUT will produce better overall results. Several test computer runs showed that CG81 should stay at one.

$$ARNUT(t) = CG81 * \min(RNUTPN, (EIMP(t) + ETSTG(t)/GTDSTO(t))/ETPOP(t)) \quad (4.13)$$

where:

CG81 = control parameter

ARNUT = average available nutrition (MT/person-year)

RNUTPN = normal required nutrition (MT/person-year)

EIMP =

ETSTG =

GTDSTO =

ETPOP =

Two pos

first is par

that discuss

4.4. The go

TDSTO (a).

a larger sa

first harves

storage for

should the

still in fo

ARHUT. Thi

outs. Equa

increased.

the TDSTO a

not violent

tions shoul

The se

vior was t

timates wi

the next h

produce an

that estim

EIMP = estimated imports (MT/year)

ETSTG = estimated total storage (MT)

GTDSTO = government desired time of storage (year) (curve (b) in Figure 4.4)

ETPOP = estimated total population (persons).

Two possible solutions to the ARNUT problem were examined. The first is part of Equation 4.13, a time-of-storage function similar to that discussed earlier. The storage time curves are graphed in Figure 4.4. The government curve, GTDSTO (b), is consistently above the rural TDSTO (a). This represents the assumption that the government desires a larger safety factor. The largest curve divergence occurs during the first harvest. The government desires a considerable increase in storage for two reasons. First, stores will be desperately needed should the second crop fail. And, since the crisis declaration is still in force, the government wants to curb overconsumption by reducing ARNUT. This should increase acquisitions and decrease sales and handouts. Equation 4.13 indicates that ARNUT will decrease if GTDSTO is increased. Note that if the assumptions leading to the divergence of the TDSTO and GTDSTO curves are correct and if the rural population is not violently opposed to government activity, then government acquisitions should be easiest during the first harvest.

The second solution explored for reducing oscillatory ARNUT behavior was to match the discontinuities of TTSH by augmenting storage estimates with crop size estimates. TTSH represents the total time until the next harvest. Adding an estimated output figure to storage should produce an idea of total food available until the next harvest. (Note that estimated imports are already a part of Equation 4.13). This second approa

formation sys

The firs

Trying to ma

in instantan

of crop size

how long to

will be avai

actual food

Urban Privat

Recall

ing acceptan

above have

modes. The

of the cons

ingly impro

possible ca

dead after

With perfec

approximate

and modelin

The mo

criteria by

trol varia

ment sales

second approach has the appealing feature of connecting extant crop information systems to the famine relief system.

The first method was chosen for its continuity and simplicity. Trying to match discontinuity to discontinuity would invariably result in instantaneous jumps in ARNUT not expected in the real world. The use of crop size presents a complicating calculation; one needs to estimate how long to hold present stores based on how soon replacement stores will be available. The lag time between the technical harvest start and actual food availability must be estimated.

Urban Private Storage

Recall the three criteria given early in this section for determining acceptance of proposed model change. The alterations described above have caused improvement in numerical values and system behavior modes. The behavior criterion is obvious, as the severe oscillations of the consumption and ARNUT curves have been removed. The most strikingly improved numerical value is the total death figure. The worst possible case, the extended price control policy,leaves 10.5 million dead after one year of an initial population of thirty-four million. With perfect data, the basic model was able to reduce the toll to approximately five million. With no parameter optimization, the policy and modeling changes produced a further drop to 3.5 million.

The modeling alterations also satisfy the third change acceptance criteria by removing urban private storage (USTOR) as a desirable control variable. Recall that the basic model decision rules for government sales and emergency feedings make use of the difference between estimated an

2.15.) The

Estimat

information

crisis, sinc

cal values i

components o

be difficult

places. A f

control var

sistently s

back contro

a common po

Positi

deaths sinc

Time series

causes over

contrast, d

duces gradu

ter prepare

classes to

overindulge

system per

most of th

death tota

The q

ducing the

estimated and desired private storage values. (See Equations 2.14, 2.15.) The relevant control parameter is CG34.

Estimated urban private storage is not a likely candidate as an information system control variable. Storage is minimal during the crisis, since food is hard for the urban classes to obtain. The numerical values in the model are consistently tiny when compared to the other components of total storage. From a real world standpoint, USTOR would be difficult to measure because there would be small quantities in many places. A further drawback is the performance of urban storage as a control variable. Even with large CG34 values, desired storage is consistently several times greater than actual storage. Desirable feedback control behavior would have actual and desired storage move toward a common point.

Positive CG34 values should have a negative impact on total deaths since urban consumption is tied directly to storage levels. Time series analysis shows that in mid-crisis, CG34 greater than zero causes overconsumption and early exhaustion of government stores. By contrast, deletion of the urban storage control (CG34 equal zero) produces gradually decreased consumption, leaving the population much better prepared for the "crunch." The larger CG34 has allowed urban classes to consume more than their allotted (ARNUT) portion. And this overindulgence continues until government supplies run out. However, system performance of the basic model was more sensitive to CG34 than most of the other parameters. Positive CG34 invariably produced lower death totals than a zero value.

The question arises why urban overconsumption was helpful in reducing the basic model death toll. One plausible explanation is that the increase

time oscilla

TTSH increas

and feeding

keep the gov

peak. And s

works poorly

The mod

and the abi

next sectio

tions of th

of problem

One po

fying poten

tem compone

It can be u

and economi

tion needed

system perf

through whe

1. Po

2. Po

3. Ir

4. A

the increased storage parameter was needed to counteract the harvest time oscillation of the old ARNUT variable. At the harvest start, TTSH increases dramatically, decreasing ARNUT at the time when sales and feeding programs are most needed. A large CG34 would be needed to keep the government programs at acceptable levels during this crisis peak. And since the parameters are time invariant, the large CG34 works poorly early in the crisis.

The modeling changes have greatly improved both numerical results and the ability of the model to match real world expectations. The next section concludes the chapter with a discussion of the implications of this study for general relief work and the relative importance of problem formulation, policy structure, and modeling accuracy.

Famine Relief Implications

One powerful use for computer simulations is as an aid in identifying potential bottlenecks in real world systems. The information system component has a similar task in modeling famine relief efforts. It can be used to determine proper modeling of demographic, nutritional and economic components and to design optimal policies. The key assumption needed is that better information quality should produce better system performance. There are several possible causes to search through when the basic assumption is violated:

1. Policy parameter values not satisfactory
2. Policy structure too weak
3. Inaccurate modeling
4. A natural phenomenon unaccounted for

A natur

harsh reali

tion early

incurred le

the future.

peak, given

mouths to f

with the sh

alive as lo

efforts for

short term

similar pat

tritional d

dicator of

harsh reali

likelihood

cannot be a

not easy ma

The la

sumption mo

sonal conse

is whether

facing a fo

do not favo

launched to

tinct polic

ple's habit

A natural phenomenon very prominent in the current study is the harsh reality of long term versus short term goals. Decreased consumption early in a crisis has several desirable results. The weight loss incurred leads to lower nutrient needs, so less food is necessary in the future. Less food eaten early means more available at the crisis peak, given a limited total supply. And more early deaths means fewer mouths to feed and better health among survivors. Hence, the conflict with the short term (two to three months) goal of keeping as many people alive as long as possible. This phenomenon plagued current modeling efforts for several months before it was realized that the effects of short term optimization must be planned for in a long term problem. A similar pattern occurs when a famine extends beyond one year; total nutritional debt at the end of the first harvest cycle is a crucial indicator of ability of the population to withstand a new crisis. Other harsh realities must be taken into account. The political climate, the likelihood of outside aid and cultural and religious responsibilities cannot be avoided by ignoring them in the planning process. These are not easy matters to deal with; there is no free lunch.

The largest improvement in system performance attendant to consumption modeling changes has definite educational implications. Personal conservation is a desirable goal. An important area for study is whether consumption habits naturally adhere to desirable limits when facing a food shortage. Two possibilities exist if cultural conditions do not favor conservation. A long term educational program can be launched to inform citizens of the benefits of moderation. Or a distinct policy structure can be designed to attempt to work around people's habits. Wise allocation policies are needed to insure that recipient gr

evidence tha

aid and reje

Pre-pla

tion. The r

ability of s

system desig

obvious.

The pla

specialties.

abounds in d

mography, go

also involve

project's ge

Perhaps

discern impo

A ledger of

two chapters

wheat from t

expended on

sampling

min

attempts

wit

wit

wit

recipient groups do not eat their allotment too quickly. There is some evidence that excessive outside aid can cause complete dependence on the aid and rejection of centuries-old famine food sources (32).

Pre-planning is basic to the approach espoused in this dissertation. The revised problem formulation of Equation 4.2 depends on the ability of system planners to examine policy structure and information system design concurrently. The interrelationships between the two are obvious.

The planning procedure calls for a team of persons with varying specialties. Just the portion of the famine relief topic examined here abounds in diversity: rural psychology, nutritional measurement, demography, government structure, communications, etc. The team must also involve the right amount of government interaction to assure the project's getting off the ground.

Perhaps the most important personal attribute needed is wisdom to discern important points from among a multitude of obscurant details. A ledger of the study time spent in securing the results of the past two chapters provides an excellent example of the need to separate the wheat from the chaff. Four research items and the approximate effort expended on each is listed below:

sampling component addition and minor modifications:	two person-months
attempts to reconcile inconsistencies:	
with problem reformulation and parameter variation:	two person-months
with policy structure:	one-quarter person-month
with modeling changes:	one-quarter person-month

The latter t

time. Certa

standing of

was not kno

The latter two avenues produced the biggest impacts and took the least time. Certainly, earlier efforts paved the way by providing understanding of the system processes, but a major roadblock to progress was not knowing what to look for.

The pr

information

5.1. The g

of the cost

from the su

ability to

real world

and the opt

Minimi

subjec

where:

$\underline{F}$

G

$\underline{X}$

$\underline{P}$

$\underline{D}_1, \underline{D}_2,$

C

CHAPTER V

THE COST FUNCTION AND INFORMATION SYSTEM DESIGN

Cost Function $G(\underline{X})$

The preceding chapter describes a mathematical formulation for the information system design problem which is repeated here as Equation 5.1. The goal of this chapter is to describe a process for generation of the cost function $G(\underline{X})$. The analysis for obtaining G is done apart from the survival model which produces performance function $\underline{F}$. The ability to adequately describe G is crucial, for this function links real world system designs to the simulation of the preceding chapters and the optimization work of later chapters.

$$\text{Minimize } \underline{F}(\underline{X},\underline{P}) \tag{5.1}$$

$$\text{subject to } G(\underline{X}) \leq \underline{C}$$

$$\text{and } \underline{D}_1 \leq \underline{X} \leq \underline{D}_2$$

$$\underline{E}_1 \leq \underline{P} \leq \underline{E}_2$$

where:

$\underline{F}$ = system objective vector (F_1 = total deaths, F_2 = total nutritional debt)

G = cost function (monetary units)

$\underline{X}$ = information quality vector (sampling frequency, measurement error, time lag)

$\underline{P}$ = policy parameter vector (rates and triggers)

$\underline{D}_1,\underline{D}_2,\underline{E}_1,\underline{E}_2$ = parameter constraints

C = budgetary constraint.

Recall

personnel,

information

This would

noted in Eq

ployed here

stage does

in the foll

Further dis

nature of f

The se

source allo

liminary wo

completed.

will do the

priorities

A mon

can be val

traditiona

proach wil

As de

formation

in the sam

derived fr

costs, den

informatio

computatio

Recall that constraints on relief system performance will include personnel, equipment, time, and money limitations. To obtain maximum information, each of these constraints should be explicitly noted. This would cause a vector $\underline{G}$ of optimization constraints and was so noted in Equation 4.2. A single-valued monetary cost function is employed here for three reasons. First, the level of complexity at this stage does not warrant separation. The system alternatives described in the following sections are very crude, a result of lack of data. Further disaggregation would not lead to significant results about the nature of famine relief resource allocation.

The second reason for adopting a single cost value is that the resource allocation problem for relief work is better analyzed after preliminary work on all subsystems (transportation, education etc.) is completed. System planners wish to place scarce resources where they will do the most good. The particular situation may dictate allocation priorities, making further analysis unnecessary.

A monetary function G is chosen because personnel and equipment can be valued in money terms. Money equivalents are often assigned in traditional cost-benefit analysis work. Note that a true systems approach will examine each constraint separately if the situation warrants.

As described in Chapter IV, it is theoretically possible that information system costs and famine relief policy costs can be considered in the same optimization problem. The two are distinct and would be derived from different sources in the current methodology. The policy costs, denoted $G_2(\underline{P})$, are generated by the survival model, while the information costs are a product of off-line analysis. The off-line computations are the main considerations of this chapter. The first section dc

could be d

possible g

considerat

consists l

gency prog

Appendix B

The g

portant li

second sec

needs anal

describes

tem costs,

fifth sect

examples co

food consum

and process

The er

sign that

proach is e

ladesh. Th

process and

any applica

geography,

cient syste

fuller flav

because its

section does, however, contain a description of policy costs as they could be derived from the survival model. The purpose is to provide a possible guide for further research; policy costs will not be a major consideration in succeeding chapters. The policy cost function $G_2(\underline{P})$ consists largely of bookkeeping equations, tracking the costs of emergency programs, grain storage, and transport. The computer model in Appendix B allows printing of the policy-related costs.

The generation of the information system cost function is the important link between real world designs and simulated performance. The second section of this chapter discusses the initial steps of design work: needs analysis and the production of system alternatives. The section also describes general necessary conditions for the relationships among system costs, and the information quality parameters $\underline{X}$. The third through fifth sections present examples of implementations of the approach. The examples cover cost functions for the surveillance of nutritional debt, food consumption and private storage, and for information transmission and processing. The last section summarizes the approach.

The emphasis here is on a methodology for information system design that could be useful in many parts of the world. Although the approach is emphasized, the discussion will focus on the country of Bangladesh. There is a danger that a general discussion would obscure the process and the amount of work needed to derive the cost function. In any application, detailed data on the country's demography, culture, geography, and economy will be needed in producing feasible and efficient system design. So a specific country is chosen to provide a fuller flavor of the proposed approach. Bangladesh is a good example because its weather and economy make it vulnerable to famine. A note on currenci

Bangladesh

There

response o

The flow o

the rural

from the r

rich at a

emergency

buy in the

An ac

able by th

actual far

acquisitio

areas and

The

grain tra

penses wo

tify thos

Of t

designed

Costs of

program

the relie

selling

incurred

on currencies is appropriate here. The base model uses the Korean won. Bangladesh has the takka. The won is used throughout this dissertation.

Policy Costs

There are three main government programs in the simulated famine response of the survival model: acquisitions, sales, and emergency aid. The flow of food in the model is generally from those with a surplus in the rural sector to the urban sectors. The government purchases grain from the rurals at a set, normal price. It then sells to the urban rich at a market price that is high due to small available supply. The emergency feeding programs are for the urban poor who cannot afford to buy in the market.

An additional food source is the small amount of imports affordable by the government. International food aid might be expected in an actual famine, but is assumed to be negliglble here. The imports and acquisitions from the rural sector are kept in government rural storage areas and shipped to the smaller urban storage areas as the need arises.

The costs to be examined are for operation of the three programs, grain transport and storage, and government imports. Some of the expenses would be incurred in normal operation; the goal here is to identify those portions attributable to famine relief operations.

Of the programs, acquisitions and emergency aid are specifically designed for famine relief, while market sales is an on-going activity. Costs of operating the former programs are relief expenses, while sales program costs are not. Grain costs and receipts must be included in the relief accounts. The government could use any profits made from selling to the rich at high prices to help cover the program expenses incurred elsewhere. There are normal average levels of transportation and storage

But the exc

should be c

limit on th

trade balan

grain is a

must be in

grams.

With

costs are

the amount

obtained b

famine. T

GAQT(

EMFT(

GSLT(

GIMT

EMTR

EMST

Where:

GAQT

GAQU

EMF

EMF

and storage whose costs are covered outside of the famine relief budget. But the excess activity generated by increased stockpiling and transport should be charged to the relief account. The survival model assumes a limit on the imports available to the country, due to a disadvantageous trade balance. Thus, the cost of locating and transporting imported grain is assumed to be a normal expense. The cost of the grain itself must be included, since this grain is sold or distributed in other programs.

With the above as background, the equations for calculating policy costs are now presented in some detail. The first task is to compute the amounts of grain involved in each activity. The grain totals are obtained by integrating the appropriate rates over the duration of the famine. The rates are model variables, presented in Equations 5.2-5.7.

$$GAQTOT(t) = \int_0^t GAQU(s)ds \qquad (5.2)$$

$$EMFTOT(t) = \int_0^t EMFDG(s)ds \qquad (5.3)$$

$$GSLTOT(t) = \int_0^t GSLS(s)ds \qquad (5.4)$$

$$GIMTOT(t) = \int_0^t GIMP(s)ds \qquad (5.5)$$

$$EMTRAN(t) = \int_0^t (GSRU(s) - GNSLS)ds \qquad (5.6)$$

$$EMSTOR(t) = \int_0^t (GSR(s) + GSU(s) - GSN)ds \qquad (5.7)$$

where:

GAQTOT = total government acquisitions (MT)

GAQU = acquisitions rate (MT/year)

EMFTOT = total distributions for emergency aid (MT)

EMFDG = emergency aid distribution rate (MT/year)

GSLTOT

GSLS

GIMTOT

GIMP

EMTRAN

GSRU

GNSLS

EMSTO

GSR

GSU

GSN

O,t

The e

is useful

figure (GN

cause the

rural sto

average s

use. The

on govern

GSN

where:

GSN

GSUD

GSRD

CG6

GSLTOT = total government sales (MT)

GSLS = sales rate (MT/year)

GIMTOT = total imports (MT)

GIMP = import rate (MT/year)

EMTRAN = excess grain transport due to famine (MT)

GSRU = urban to rural transport rate (MT/year)

GNSLS = normal government sales rate (MT/year)

EMSTOR = excess storage due to famine (MT/year)

GSR = government rural storage (MT)

GSU = government urban storage (MT)

GSN = normal government storage (MT)

0,t = time limits on duration of famine.

The equations are all straightforward, but a word of explanation is useful for Equations 5.6 and 5.7. The non-famine government sales figure (GNSLS) is used as proxy for the normal transportation rate because the grain sold in the urban market must first be shipped from rural storage. So the average transport rate should be close to the average sales rate to avoid frequent shortages or inefficient vehicle use. The normal storage amount, GSN, is computed in Equation 5.8 based on government target storage levels.

$$GSN = CG60 * (GSUD + GSRD) \qquad (5.8)$$

where:

GSN = normal government storage (MT)

GSUD = desired government urban storage (MT)

GSRD = desired government rural storage (MT)

CG60 = storage parameter (dimensionless).

Unit c

total costs

price (PFDR

priate calc

puted simil

grain purch

sector is c

distributic

The amount

tions (EMFT

Equation 5

CGAQ(t

CEMFD

where:

CGAQ

PFDRN

CGAP

GAQTO

CEMFD

CGFP

EMFTC

PWLD

ER

Extra

wide range

tuitous re

Unit cost parameters are multiplied by grain totals to ascertain total costs. Acquisition expenses are based on a fixed grain unit price (PFDRN) plus an average program cost per unit (CGAP). The appropriate calculations are in Equation 5.9. Emergency aid costs are computed similarly, but care must be taken to avoid double-counting the grain purchases. It is assumed that grain acquired from the rural sector is distributed through the emergency aid program. Additional distributions beyond the rural acquisitions must come from the inputs. The amount will be the difference between distributions and acquisitions (EMFTOT-GAQTOT). The price is the current world price PWLD. Equation 5.10 contains the emergency aid cost function.

$$CGAQ(t) = GC61 * (PRDRN + CGAP) * GAQTOT(t) \qquad (5.9)$$

$$CEMFD(t) = CG62 * (CGFP * EMFTOT(t) + PWLD*ER*(EMFTOT(t) - GAQTOT(t))) \qquad (5.10)$$

where:

CGAQ = acquisitions cost (won)

PFDRN = fixed purchase price for acquisitions (won/MT)

CGAP = acquisitions program cost (won/MT)

GAQTOT = total government acquisitions (MT)

CEMFD = emergency aid cost (won)

CGFP = emergency aid program cost (won/MT)

EMFTOT = total emergency aid (MT)

PWLD = world food price ($/MT)

ER = currency exchange rate (won/$).

Extra factors (CG61 and CG62) are included to account for the wide range of feeding programs possible. Some sources note that gratuitous relief should be avoided, as it has a demoralizing effect on recipients

done on go

tion. An a

sixty-nine

(58). Thu

ful planni

are used

to relief.

through wo

The s

the differ

and buying

in Equatio

integrand,

CGSLS

where:

CGSLS

PFD

GSLS

The

price cei

fect tota

a price c

by compet

and opini

on non-go

recipients (53). An alternative proposal is to pay with food for work done on government organized projects, such as road or well construction. An account of the Bihar, India, famine of 1967-68 claims that sixty-nine percent of the relief costs were spent for productive work (58). Thus, the drain on the total budget can be alleviated with careful planning and well organized projects. The parameters CG61 and CG62 are used to compute the proportion of program cots attributable solely to relief. So CG61 = 1.0 would indicate that no benefits were derived through work-for-food programs.

The sales program actually generates revenues. The net income is the difference between selling at the inflated domestic market price and buying on the unaffected world market. Total income is calculated in Equation 5.11. Note that the food price is included as part of the integrand, as it varies with time.

$$CGSLST(t) = \int_0^t PFD(s) * GSLS(s)ds \qquad (5.11)$$

where:

CGSLST = receipts from government sales (won)

PFD = domestic food price (won/MT)

GSLS = government sales rate (MT/year).

The sales revenue depends heavily on food price. Any type of price ceiling will greatly affect government income. It will also affect total death figures, as discussed later in Chapter VII. Setting a price ceiling is an important government decision area, influenced by competing considerations of inflation, equitable food distribution, and opinions of the populace. Such a ceiling is difficult to enforce on non-government sales. Because revenues are greatly affected by a decision th

will be kept

sibility do

very high p

for relief

The to

sitions pro

Equation 5.

CPROG(t) = (

where:

CPROG =

CGAQ =

CEMFD =

One add

Part of the

penses in E

nues to obt

concern her

cision cons

bought at t

CGIMP(t

where:

CGIMP

PWLD

ER

GIMTOT

decision that lies outside the direct focus of this study, the revenues will be kept separate from the policy costs $G_2(\underline{P})$. An interesting possibility does suggest itself here. By selling grain to the rich at very high prices, the government may be able to use the revenue to pay for relief programs. Such a plan is worth considering.

The total program cost will be the sum of emergency aid and acquisitions programs, since the sales program is to be counted separately. Equation 5.12 presents the required summation.

CPROG(t) = CGAQ(t) + CEMFD(t) (5.12)

where:

CPROG = total program cost (won)

CGAQ = acquisitions cost (won)

CEMFD = emergency aid cost (won).

One additional program cost is noted, that of government imports. Part of the import cost enters the calculation of emergency aid expenses in Equation 5.10. The rest will be deducted from sales revenues to obtain a net sales figure. Since revenues are not of major concern here, the total import cost is presented as an important decision consideration outside the scope of the model. The grain is bought at the prevailing world price, as computed in Equation 5.13.

CGIMP(t) = PWLD * ER * GIMTOT(t) (5.13)

where:

CGIMP = import total cost (won)

PWLD = world food price ($/MT)

ER = currency exchange rate (won/$)

GIMTOT = total imports (MT).

The t

derived in

reflect th

less than

CGSRU

CSTOF

where:

CGSRU

CRUT

EMTRA

CSTO

CHI

EMST

The

ming the

G_2(P

where:

G_2

P

CPRa

CGSI

CST

Not

rectly d

model, w

The transportation and storage costs are straightforward and are derived in Equations 5.14 and 5.15. A maximization function is used to reflect the fact that the relief account would not be credited when less than normal levels are shipped or stored.

$$CGSRU(t) = \max(0.0, CRUT * EMTRAN(t)) \quad (5.14)$$

$$CSTOR(t) = \max(0.0, CHI * EMSTOR(t)) \quad (5.15)$$

where:

CGSRU = famine transportation cost (won)

CRUT = unit transport cost (won/MT)

EMTRAN = grain transport due to famine (MT)

CSTOR = famine storage cost (won)

CHI = unit storage cost (won/MT-year)

EMSTOR = storage due to famine (MT-year).

The policy cost function is now derived in Equation 5.16 by summing the totals from Equations 5.12, 5.14, and 5.15.

$$G_2(\underline{P}) = CPROG + CGSRU + CSTOR \quad (5.16)$$

where:

G_2 = policy costs (won)

$\underline{P}$ = policy parameter vector

CPROG = program costs (won)

CGSRU = transportation costs (won)

CSTOR = storage costs (won).

Note that none of the equations described in this section is directly dependent on $\underline{P}$. The parameters affect the rates in the survival model, which enter the cost function through Equations 5.2-5.7.

The o
dard nutri
this disse
discussed
monograph
systems sh
expands th
limit the

The c
of a syst
Chapter 2
limits an
is define
tive meth
posed. A
ble for p
be to eva
alternati
tion erro
by intui
and syst
world ou

An
use of a
natives
and cost

Information System Design

The objective of this section is to examine the place of the standard nutritional surveillance design process in the overall approach of this dissertation. The process for continuous surveillance has been discussed in several places, notably a World Health Organization (WHO) monograph (10, 25). The WHO recommends that famine relief information systems should be a special case of on-going surveillance. This greatly expands the possible scope of system design, but we will continue to limit the discussion to the case of severe food shortages.

The contents of the WHO monograph can be placed in the context of a systems approach to the design of a surveillance system (40, Chapter 2). The first step is to analyze information needs. The limits and components of the system are identified, then the problem is defined based on the real world variables to be estimated. Alternative methods for collecting and communicating the information are proposed. An initial screening eliminates alternatives that are infeasible for political, cultural, or physical reasons. The next step should be to evaluate the economic and financial feasibility of the remaining alternatives. This evaluation is generally done by minimizing information error for a given budget cost. Variables to be sampled are chosen by intuition and experience. The performance of the selected variables and system alternatives is evaluated through time by observing real world outcomes.

An altered approach is suggested in the current methodology. The use of a computer simulation allows initial evaluation of system alternatives using both costs and performance criteria. The system design and cost analysis phases are done off-line from computer performance model and (

the cost a

meter vect

5.17. Not

cost alter

than for (

$G(\underline{X})$

subj

where

G

$\underline{X}$

a_i

C_{a}

E_1

Re

ponents

cessin

assessm

collec

quirem

questi

superv

stati

progr

nolog

model and optimization work. An additional qualification is added to the cost analysis, minimizing costs for the information quality parameter vector X. The process is described mathematically in Equation 5.17. Note that the members of $\underline{X}$ are continuous variables, so minimum cost alternatives are chosen for regions of the vector space, rather than for discrete vectors.

$$G(\underline{X}) = \underset{a_i}{\text{minimum}}\ C_{a_i}(\underline{X}) \qquad (5.17)$$

$$\text{subject to } \underline{E_1} \leq \underline{X} \leq \underline{E_2}$$

where

G = information system costs

$\underline{X}$ = information quality parameter vector

a_i = ith system alternative, i=1,2,...,K

C_{a_i} = cost of a_i, dependent on $\underline{X}$

E_1, E_2 = information quality constraints.

Recall the information system identified in Figure 1.1. The components to consider in the design phase are data collection; data processing and transmission; program evaluation and the interpretation, assessment, and storage of data at the system manager's level. Data collection involves the methods, number of samples, and personnel requirements from the sampling design; the format of data reports and questionnaires; training for surveillance teams; and provision for supervision and quality control (25). The processing component must statistically analyze the accumulated raw data. Microcomputers or programmable calculators may be powerful pieces of appropriate technology for use here. Data transmission design depends on the institution

sonnel avai

munication

The s

need to as

They must

large and

ters as ar

cussed in

Data

including

managemen

Alte

data wil

are dete

data ite

stages c

Informat

Cos

The mai

sample

expense

cost to

specia

nel co

traini

institutional structure of the country and on equipment and personnel available. The structure dictates the needed lines of communication, while physical resources determine the communication methods.

The system managers are not just programmed decision makers; they need to assess conditions based on numerous pieces of information. They must be able to interpret the significance of tables, charts, large and small changes in variables, etc. The use of information filters as an aid to system managers in assessing true conditions is discussed in Chapter VI.

Data storage is vital to evaluation of overall relief activities including policies, the information system, and the field programs. A management decision needs to be made on the use of computers for storage.

Alternative system designs must include not only the stages that data will follow, but the data items themselves. The information needs are determined along with policy structure. Once specific desired data items are known, the collection, transmission, and processing stages can be tailored to fit requirements.

Information System Costs

Costs of separate processes and stages are difficult to identify. The main variable expenses will be due to personnel, equipment, and sample design. Generally, the total salary or purchase price for an expense is known. The difficulty comes in assigning a portion of the cost to the relief account. If the famine surveillance system is a special case of regular surveillance, then total equipment and personnel costs can be shared by the similar functions. Some expenses, like training and planning, may be incurred long before an actual famine.

Some of the
the famine.
and the pa
will be al
tions will
of the cos

In ge
The impor
developed
informati
alternati
informati

It s
of the r
quality
ponent.
time) li
cal Cost

As
sengers
lag tim
telepho
large m
cost w
ment d
for mi

Some of the equipment expenses are fixed regardless of the extent of the famine, while other items vary both with the severity of the crisis and the particular design chosen. Another complication is that costs will be allocated differently in different countries. Several assumptions will be discussed later in this section to better define the scope of the cost analysis for this dissertation.

In generating the cost function $G(\underline{X})$, three items must be linked. The important middle link is the set of specific system alternatives developed in the design process. The other two links are the costs and information quality related to the alternatives. One starts with the alternatives and develops the G function by minimizing costs for given information quality.

It should be useful at this point to examine Table 5.1 for examples of the relationships among system alternative components, information quality parameters and costs. The key to the table is the System Component. The $\underline{X}$ Parameters (sampling frequency, measurement error, lag time) likely to be affected are given in the second column. The Typical Cost Significance column describes ties among the three links.

As an example, two possible communication devices would be messengers or telephones. The primary $\underline{X}$ parameter affected would be the lag time, unless common carelessness introduces significant error. The telephone alternative would have high initial costs and would incur large maintenance expenses for the first years of use. But the total cost would, hopefully, be shared by many businesses and other government departments. The telephone (or something similar) would be needed for minimal delays.

System Co

Sample de

Data col
Personne

Travel
arrangem

Communic
equipmen

Communic
personne

Data st

Table 5.1. Relationships Among Information Quality, System Alternatives, and Costs.

System Component	Parameters	Typical Cost Significance
Sample design	Sampling frequency, delay, sampling error	Error affects number of observations; cost = # surveys * cost/survey; cost/survey = cost/observation * observation/survey; processing techniques may introduce bias
Data collection Personnel	Delay, error	More personnel reduces delay, but costs more
Travel arrangements	Delay	Faster travel reduces delay, costs more
Communication equipment	Delay, error	Technical equipment reduces delay, costs more; reliability costs more
Communication personnel	Delay, error	Training cost important
Data storage	Sampling frequency, error, delay	More sampling means larger storage; faster retrieval reduces delay

The m

done to de

number of

telephone

al altern

telephone

Cost Func

The

useful.

formatio

ternativ

tified w

problem

through

nents a

"best"

dated.

system

Tw

functic

tives v

dividi

than t

will l

lines.

limits

The main messenger cost would be for personnel. Studies could be done to determine the optimal design for quick service with a minimum number of messengers. This is likely to be much less expensive than telephones, but the delay time is increased. Note that several additional alternatives could be generated as combinations of messenger and telephone use levels.

Cost Function Characteristics

The function $G(\underline{X})$ will have several characteristics if it is to be useful. There must be a well defined relationship between specific information quality parameter values $\underline{X}$ and the unique optimal system alternative that provides that quality level. Each vector $\underline{X}$ must be identified with one alternative, since the solution of the optimization problem of Equation 5.1 will be an $\underline{X}$ vector. It would be useless to go through the optimization process and derive a vector whose delay components and error components indicate competing alternative systems as the "best" choice. Another necessary attribute of $G(\underline{X})$ is that it be validated. That is, some testing must be done to insure that the chosen system alternatives actually do provide the cited information quality.

Two statements can be made about the probable form of any $G(\underline{X})$ function. The first has been mentioned previously: system alternatives will be optimal for whole regions of the $\underline{X}$ vector space. The dividing lines will be hyper-planes in the space of one less dimension than the vector $\underline{X}$. A second statement on the form of $G(\underline{X})$ is that it will likely not be differentiable but may be continuous at the dividing lines. Discontinuities could occur when one alternative reaches the limits of its physical constraints. An example is the necessary minimal de

mission.

discontin

The

complexit

necessary

be cyclic

tify gene

sequent

quality

Then a s

defined

Simplify

Sev

rest of

position

the man

second,

to the

Th

has bee

and is

ables

sumpti

in Cha

inform

minimal delay inherent in the use of messenger service for data transmission. A further decrease in delay time may require a substantial discontinuous jump in costs.

The G(X) function can be constructed at many different levels of complexity. A general guideline to follow is to use only the complexity necessary at each stage of the design process. The overall project will be cyclical in nature. A first pass at the cost function should identify general costs to allow an idea of the tradeoffs to be faced. Subsequent optimization work will give estimates of desired information quality and should eliminate some of the original system alternatives. Then a second, more specific cost analysis can be done with more well-defined objectives.

Simplifying Assumptions

Several assumptions are presented here to focus the study of the rest of this chapter. There is a twofold purpose for making these suppositions. First, they will provide needed limits on the discussion; the many possible cases to explore would fill numerous volumes. And second, it is hoped that the assumptions will provide some insight into the kinds of decisions faced in actual cost analyses.

The first assumptions have already been mentioned. Bangladesh has been chosen as the region to study. This country is famine-prone and is much like other endangered areas in Southern Asia. The variables on which data will be collected are nutritional debt, food consumption, and rural private food storage. These variables were chosen in Chapters III and IV as the survival model was modified to include information system evaluation.

tion
tions
ties
in th
to o
syst
othe
coll
bett
tio
zen
to
lar
rel
pl
st

ad
ti
a
p
v

(
(

Several suppositions are made about the portions of the information system (see Figure 1.1) to be included in cost function considerations. Specifically, the evaluation component, data storage capabilities and communications back to the affected peoples will be excluded in the current study. It is felt that these items are heavily linked to other systems and to planning outside the famine relief information system. Program evaluations will be made using much data collected for other purposes. The chief costs should then be for personnel and the collection of quality control data. The evaluation component would be better considered along with specific program design (feeding, sanitation, health, etc.). Similarly, although it is important to keep citizens aware of famine extent and relief development, this ties closely to the operation of relief programs. Data storage capabilities must be large enough to include many pieces of information distinct from famine relief. Since the famine records will not be useful without further planning for future food shortages, the storage function should be studied as part of a long range continuous surveillance system.

System manager salaries are an important cost, especially if the administrative heads are given special responsibilities for the duration of the famine. But this expense is considered to be part of overall relief, not assignable to information system cost. However, the procedures of the managers, discussed in Chapter VI, will influence the vector $\underline{X}$, which will indirectly affect the cost function.

The preceding limiting assumptions have focused attention on costs for collection, processing, and transmission of nutritional debt, consumption, and private storage data. The interrelationships of these tasks allow several simplifications in translating the system alternati

processi

sampled

additive

and proc

of meas

in info

A

the sam

is, the

surveys

of des

relate

S

cation

avoide

transm

tion

chara

line

defi

time

tion

tran

ties

the

alternatives to information quality parameters. Data collection and processing can be considered together for error purposes. The various sampled variables can be transmitted through the same channels to avoid additive costs. The sample design should cover both data collection and processing. These two operations will constitute the main source of measurement error. So for cost function purposes, the error terms in information quality vector $\underline{X}$ will apply only to the sample design.

A point to build from in constructing the cost function is that the sampling frequency can be separated from measurement error. That is, the total surveillance cost equals the product of the number of surveys and the cost per survey. The cost per survey is a function of desired measurement error, while the number of surveys is inversely related to the sampling frequency.

Sampling frequency will affect transmissions only if the communication channels are overloaded. If we assume that such practices are avoided, then the delay parameter of $\underline{X}$ is the only one affected by the transmission component. It is further assumed that two-way communication between the field programs and system managers is a necessary characteristic of system design.

The delay parameter of $\underline{X}$ provides an example of the use of off-line analysis to simplify later optimization work. The total delay is defined as the lag between the time test observations are made and the time that system managers receive summarized reports of the observations. The lag can be roughly broken into a measurement delay and a transmission delay. These delays are related to two separate activities, so that the desired final optimum is the "best" combination of the activities. There are two ways of handling the combination problem

As part
cost com
delay le
that the
overall
the off-
of para
the der
survey
paramet
versus
which i

T
teams
tions,
proces
one-ti
Equati

(

where

(

As part of the cost function optimization, one can find the minimum cost combination of measurement and transmission methods for each total delay level. Or two separate delay parameters can be assigned in $\underline{X}$ so that the optimal delay combination is discovered as a by-product of the overall optimization. We assume here that the decision is handled with the off-line cost function analysis. This helps to minimize the number of parameters needed in the final optimization. Note, however, that the derivation of the cost function can become extremely complex. The survey method affects not only the delay parameter, but also the error parameters. There may be tradeoffs in providing smaller delay costs versus smaller error costs. A smaller error requires more observations, which increases the delay time.

Nutritional Surveillance Costs

To collect data on the nutritional level of the population, trained teams of observers will conduct sample surveys. The number of observations, the villages to visit, recording techniques, and statistical processing are all part of the sample design. With the inclusion of one-time fixed expenses, a crude cost function can be derived as in Equation 5.18. Note that SDND, DELD, and SAMPT are all members of $\underline{X}$.

$$\text{CNS(TF, SDND, DELD, SAMPT)} = \text{CFIXN} + \text{TF} * \text{CSURN(SDND, DELD)/SAMPT} \tag{5.18}$$

where:

CNS = cost of nutritional surveillance (won)

CFIXN = fixed cost of nutritional surveys (won)

CSURN = cost per nutritional survey (won/survey)

SDND = nutritional debt measurement standard error incur

be pr

leve

Seve

tica

surv

port

Indi

cal,

subj

have

gene

rap

more

vit

tat

(23

dis

Pro

cr

DELD = delay (years)

SAMPT = nutritional sampling interval (years/survey)

TF = time duration of famine (years).

The problem now is to determine the fixed costs and survey costs incurred when measuring nutritional debt. Background information will be presented on methods commonly used for assessment of nutritional level and on relevant social and physical conditions in Bangladesh. Several natural methodological choices present themselves. A statistical sampling technique is then presented which allows an estimate of survey costs based on the chosen measurement methods. The result is a portion of the information system cost function.

Indicators of Acute Malnutrition

There are four nutritional measurement types: clinical, biochemical, tissue, and anthropometric (23). In general, clinical tests are subjective and highly variable, while biochemical and tissue tests have extensive time, facility, and personnel requirements. There is a general consensus that anthropometric measures are most efficient for rapid assessment of acute malnutrition. The other methods have been more useful in evaluating long term, chronic malnutrition involving vitamin and other deficiencies.

Children (to the age of ten) are almost always taken as representative of the entire population for acute malnutrition surveillance (23). The young, with their high growth rates and susceptibility to disease, are the first to show appreciable signs of malnourishment. Protein-calorie malnourishment (PCM) is the main concern in a food crisis. Vitamin and other deficiencies are secondary in the short run.

A cau

the p

patt

of m

is t

rovi

tive

pro

alb

ser

for

to

cr

ca

ra

fr

i

c

(

A caution in using children as representative is to determine whether the particular society has preferential in-family food distribution patterns that would bias results.

Eleven clinical signs have been identified as possible indicators of malnutrition (14). The main objection to quick clinical examinations is the inherent subjectivity. However, it could be possible to have roving teams of clinicians each sampling in several areas for comparative purposes. Such an approach has not surfaced in the literature, probably because of the common call for standardization.

Typical biochemical tests would be for amino acid imbalance, serum albumin, and urinary creatinine. The practical aspects of sample preservation, personnel, and equipment make such tests highly infeasible for quick work. In addition, the results are often unsatisfactory due to wide variability in PCM syndromes.

Tissue measurements are probably also impractical for use during crises. It is claimed that "hair root diameter is the first morphological adaption to experimental protein deprivation" (9). But the most rapid hair root measurement calls for a microscope and relatively careful sample collection, both of which are generally scarce commodities in the field.

Anthropometry includes several quick and reliable nutritional indicators. The so-called "big six" are weight, height, arm, head, and chest circumferences and triceps fat fold. A common indicator is derived from taking the ratio of measurements for two distinct body elements. One element must be sensitive to recent periods of low consumption (arm circumference, body weight) while the other should be little affected by short term conditions (height, head circumference). The most

tios

back

tran

ing

iab

etc

ext

ter

tap

or

al

ca

fe

me

of

ch

fe

h

w

s

i

n

most widely used indicators are weight, arm circumference, and the ratios of these two with height.

Weight measurement requires an appropriate scale. Possible drawbacks of a scale for fieldwork are required maintenance, testing, and transport. A study of the causes of measurement variability in obtaining body weight of children attributes ninety-nine percent of the variability to short term variation in the child (bladder, gut contents, etc. (66). The same study concluded that weight alone could identify extreme cases of protein-calorie malnutrition but is not useful in determining mild to moderate PCM.

Limb and other circumferences are easily obtained with a simple tape. The best tape is narrow fiberglass to avoid fraying, breaking, or stretching the tape or breaking the skin of the subject (24).

A fairly recent invention of the Quaker Service Team in Nigeria allows measurement of arm circumference (AC) and height and a quick calculation of their ratio (4). The so-called QUAC (Quaker Arm Circumference) stick is a height measuring stick which is marked off in arm measurements rather than height. Cutoff values for a specified percent of expected AC for the given height are marked on the stick. If a child is taller than the level on the stick where his/her arm circumference is found, the child's arm is thinner than the average child of his/her height and is judged to be malnourished. By observing only walkers, one avoids the problem of defining correct baby length measurement. With a simple modification, the tape can be used as a recording device to be analyzed later (69).

The QUAC stick has been used to identify two or three levels of malnutrition, generally given as percentages of a standard value. The

QUAC
dual
chil
tati
show
and

the
bin
and
of
can

tec
wid
ind
if
her
men
pac
sex
tio

giv
spo
plo
Pil

QUAC can also be used as a screening device to identify specific individuals in need of extra care. Since the stick's figures are set and a child's AC changes very slowly (compared to weight), the critical limitation on measurement variability is correct technique. Studies have shown an average three percent variation in one measurer's results (24) and a maximum of eight to ten percent variance between observers (3,36).

To obtain a skinfold measurement, calipers are needed. These have the disadvantage of being hard to use and relatively expensive. By combining skinfold and AC measurements, the cross sectional areas of fat and muscle can be determined (43). This allows an estimate of the type of PCM prevalent. As in many of the anthropometric measures, edema can be a complicating factor here.

Several difficulties are inherent in the use of anthropometric techniques. In the countries where acute malnutrition is likely to be widespread, exact age levels are seldom known. This requires age-independnet indicators. A nutritional survey can be best interpreted if baseline data exists and a normal desired status is defined. The hereditary effects on body dimensions must be separated from environmental malnutrition. Factors other than malnutrition which have an impact on body dimensions include socioeconomic status of the parents, sex and birth rank of the child, climate, seasonal variation, infections, parasites, and psychological factors (23).

Recent reports of nutritional assessment in areas of known famine give strong support for the use of the QUAC stick. A study in Biafra, sponsored in part by the United States Center for Disease Control, explored various methods for determining relief allocation quantities. Pilot surveys were conducted using six indicators: kwashiorkor hair

cha
hei
tec
wor

ter
pre
chi
the
qui
two
not
as
the

was
dua
til
con
tio

changes, edema, clinically established malnutrition, estimated age/ AC, height/ weight, height/ AC. These represent a broad range of available techniques. The QUAC stick ratio of height/AC was chosen for later work because it is:

1. Reproducible and accurate
2. Simple enough to be performed by unskilled workers under supervision
3. Economical
4. Able to yield three levels of malnutrition (mild, moderate, severe)
5. Rapidly performed
6. Based on objective rather than subjective standards (15)

The above survey covered sixty villages in one month without interrupting routine relief activities. A team of three people (interpreter, secretary, measurer) could survey a minimum of seventy-five children of a village in one to three hours. A similar use was made of the QUAC stick in a different region of Nigeria (36). By using a quicker (and probably less accurate) sampling technique, an average of two hundred children were examined by two people in one hour. This did not include sample selection or travel times. In addition to serving as a basis for mass feeding allocations, the method was used to screen the severely malnourished for later examination by a physician.

Quac stick measurement of more than 8,000 children in Bangladesh was followed eighteen months later by a study to determine the individuals' fates. A clear picture emerged as those in the lowest percentiles of AC/height stood the greatest risk of dying (62). The study concluded that the QUAC stick provides an accurate measure of nutritional level. It also provided evidence that the predictive value of th

go

in

ta

ma

mo

cl

si

Re

in

ul

pe

of

th

La

li

ti

of

Ge

ma

il

st

the measurement decays with time. That is, old information is not as good as new information.

One article does report on the use of the weight/height ratio during a food crisis (20). A brief clinical exam and questioning on mortality rates were also included. The survey lasted ten weeks. The main result was a change in the food distribution patterns to cover more thoroughly those regions furthest from the capital. It is not clear whether this long-term survey was able to accommodate emergency situations.

Relevant Social and Physical Factors in Bangladesh

Several factors will greatly influence the success of any system implemented in Bangladesh. The country is one of the most densely populated and poorest in the world. Approximately seventy-five million people live in a land area the size of Louisiana. There are an average of one thousand people per square mile. Fifteen to thirty percent of the land mass is flooded during the monsoon months from May to August. Land communication and transportation are sorely lacking (57).

Ninety-five percent of the people live in small villages. Most live in extended households, and there are generally two or three factions or household groupings in each village (68, Chapter 5). Sharing of food is common within factions and often within the entire village. Generally heads of households receive the largest food portions, as a mark of their positions. The population is largely undereducated and illiterate; many graduates migrate to the cities.

It is clear from the above explanatory material that the QUAC stick can be very useful in the assessment of malnutrition in

Bang
nont
with
that
feed
deve
grap
tion

expe
form
the
invo
of S
range
of o

abun
smal
the
from
as a

Opti

the
trav

Bangladesh. The method fits the population in that it is relatively nonthreatening to the subjects being measured and it can be administered without a great deal of training. There is the additional advantage that the QUAC can be used as a screening device to reduce costs in feeding and health programs. Finally, the QUAC stick can be used to develop an objective and comparative nutritional index across geographical and economic classes. This is in accord with the equalization policy structure of the survival model.

The assumption is made here that the QUAC stick will be the least expensive assessment tool for any feasible range of the applicable information quality parameters. This allows several simplifications in the cost function analysis. The cost per survey variable CSURN will involve only one technique; there is no need to determine the levels of SDND and DELD that separate distinct system alternatives. A whole range of SDND and DELD values can be constructed on the basis of number of observations and personnel use.

The QUAC stick technique is quick and simple, and there is an abundance of subjects available. Measurement time will likely be very small, as long as a sufficient number of survey teams are used. Thus, the delay parameter, DELD, of $\underline{X}$ will have a negligible contribution from nutritional debt surveillance. This allows us to consider CSURN as a function of SDND only (see Equation 5.18).

Optimal Survey Costs

As mentioned earlier, the cost of a sample survey is related to the number of observations to be made. Equipment, personnel, and travel expenses can be summed and divided by the number of unit samples

to
th
me
pr
re
co
gr
po
As
wh
mi
ca

to obtain a cost per observation figure. A general statistical fact is that the number of observations required is inversely related to the measurement variance.

In sample surveys, stratification of the subjects is often done to provide subgroups that are homogeneous. The <u>a priori</u> groupings help to reduce the expected sampling error. For nutritional surveillance, common bases for stratification have been geographical area, population group, and biological status (age, sex, etc.) (25).

If the survey cost can be stated in a simple form, it is often possible to obtain a sample design with optimal cost and variance. Assume that costs are of the form of Equation 5.19.

$$CSUR = C_0 + \sum_{h=1}^{L} C_h n_h \qquad (5.19)$$

where:

$CSUR$ = survey cost (won/survey)

C_o = fixed survey cost (won/survey)

C_h = sample cost, stratum h (won/sample)

n_h = number of observations, stratum h

L = number of strata.

Given such a linear cost function, it is possible to compute a minimal cost for specified variance (13, Chapter 5.5). The necessary calculations are given in Equations 5.20-5.22.

$$n_h = \frac{1}{V} * (W_h S_h / \sqrt{C_h}) * (\sum_{h=1}^{L} W_h S_h \sqrt{C_h}) \qquad (5.20)$$

$$n = \frac{1}{V} * (\sum_{h=1}^{L} W_h S_h \sqrt{C_h}) * (\sum_{h=1}^{1} W_h S_h / \sqrt{C_h}) \qquad (5.21)$$

$$CSUR = C_0 + \frac{1}{V} * (\sum_{h=1}^{L} W_h S_h \sqrt{C_h})^2 \qquad (5.22)$$

whe

mate
of c
as s

root
form
nutr
cabl
must
tain
look

Bangl
other
has f

where:

n_h = number of observations, stratum h

n = total observations

CSUR = survey cost (won/survey)

W_h = population proportion, stratum h

S_h = population standard deviation, stratum h

C_h = sample cost, stratum h (won/sample)

L = number of strata

C_0 = fixed survey cost (won/survey)

V = variance of survey mean.

Note that stratum size and population standard error must be estimated along with the observation cost of the strata. The optimal number of observations in each stratum increases as stratum size increases or as stratum internal variability increases.

The information system standard error parameter SDND is the square root of the survey variance V, relating cost (Equation 5.22) to the information system. To determine whether this form can be used for the nutritional survey problem, the form of Equation 5.19 must be applicable and the parameters W_h, S_h, C_h, and C_0 from Equations 5.20-5.22 must be available. The population proportions W_h can be easily obtained from census materials (12). The other items require a further look at likely conditions in Bangladesh.

Let us first examine the state of the communications network in Bangladesh as of 1973. The capitol, Dacca, is connected to each of the other regional centers by modern microwave facilities. Each region has five or six "base" towns connected to the regional center by an

ol
he
re
ti
de
wi
av
on
pl
im

ta
su
Ch

po
me
gi
Es
of

rec
add
to
the
tha

old UHF network. The "bases" are natural choices for surveillance headquarters. A survey team operating out of each base town would be responsible for a small region of the country. Given the transportation obstacles present in Bangladesh, the use of many teams seems prudent. This also supports the assumption that measurement delay time will not be significant. The nutritional survey teams would then be available for other types of surveillance. It will be assumed that one team operates out of each base town and that one survey can be completed in one to three days. Note that this assumption bypasses the important problem of optimal surveillance personnel use.

The use of many survey teams leads to relatively small transportation costs. This is important for the use of Equation 5.19 since substantial travel expenses require a different formulation (13, Chapter 5).

The remaining consideration is estimation of the nutritional debt population standard error S_h. This should not be confused with measurement standard error SDND. S_h^2 represents the variation inherent in the given stratum. Baseline studies can help to estimate this quantity. Estimates are also available if the range and approximate distribution of possible values are known.

The variance problem here is twofold. First, the survival model requires the variance of per-capital nutritional debt requirements. An additional error is introduced in translating QUAC stick measurements to nutritional debt levels. Based on successful past experiences with the QUAC stick, it appears that the needed translation can be done and that increased sample size reduces the expected error.

For the purposes of the current model, initial estimates of S_h^2 values will be made according to Cochran (13, Chapter 4.7). The form of this estimate is given in Equation 5.23. It will be assumed that maximum and minimum per-capita nutritional debt values are known and that the distribution in the population is similar to an isoceles triangle. The nutritional debt variance estimate will be increased to reflect the randomness inherent in Quac stick use. The amount of increase is set to provide reasonable results, based on descriptions of QUAC surveys in the literature.

$$S^2 = RANGE^2/24 \qquad (5.23)$$

where:

S^2 = nutritional debt variance in population

RANGE = difference between maximum and minimum nutritional debt values.

An additional consideration that could be examined in later studies is the effect of measurement variance among observers on the optimal number of survey teams. This has been avoided here by the assumption of one team at each base. If the variance among observers is known and a cost function can be constructed as in Equation 5.24, then the number of observers and unit samples to minimize costs can be determined for a given variance (56, Chapter 8.5).

$$CSUR = C_0 + C_1 * n + C_2 * m \qquad (5.24)$$

where:

CSUR = survey cost (won)

C_0 = fixed cost (won)

C_1 = unit sample cost (won/sample)

four
tner
of t
ly a
Cost
tion
5.26
that
gion
down
dif
era

whe

C_2 = observer cost (won/observer)

n = number of samples

m = number of observers.

The survival model requires nutritional debt estimates for each of four economic classes, each estimate having the same variance. Thus, there are only four strata representing the nutritional standard error of the population. It will be assumed that the classes are spread evenly across the four regions, so that four population strata will suffice. Costs vary by region and by class. With these definitions, the nutritional debt surveillance costs are summarized in Equations 5.25 and 5.26. One further note is that CSURN is computed with the assumption that each population class represents a separate survey and the four regions are the statistical sampling strata. The reason for this breakdown is the possibility that different error rates could be allowed for different classes, particularly a rural and urban breakdown. This generality is not used in the current study.

$$CSN(TF,SDND,SAMPT) = CFIXN + TF * CSURN(SDND)/SAMPT \tag{5.25}$$

$$CSURN(SDND) = CN_0 + \frac{1}{SDND^2} * \left(\sum_{j=1}^{4} SN_j^2 \sum_{h=1}^{4} W_h \sqrt{CN_{hj}} \right)^2 \tag{5.26}$$

where:

CSN = nutritional surveillance cost (won)

CSURN = nutritional survey cost (won/survey)

TF = time duration of emergency (years)

SDND = nutritional debt measurement standard error

SAMPT = nutritional survey frequency (years/survey)

CFIXN = fixed nutritional surveillance costs--training and equipment (won)

Appen

dix

comp

equi

incu

is g

wher

The

men

clu

gio

and

CN_h

CN_0 = fixed nutritional survey cost--equipment (won/survey)

W_h = population proportion, stratum h

SN = population nutritional standard error

CN = nutritional unit sample cost (won/sample)

j = index on population classes

h = index on statistical strata.

The exact parameter values used in modeling work are explained in Appendix A and can be located in the FORTRAN computer program in Appendix B. The following designations have been made to simplify numerical computations. Surveillance fixed cost CFIXN includes training and equipment (QUAC sticks). The fixed equipment and training costs are incurred once. The form used for calculating the fixed cost function is given in Equation 5.27.

$$CFIXN = TEAMS * (TRAINN + EQN * PMNT) \quad (5.27)$$

where:

CFIXN = fixed nutritional surveillance cost (won)

TEAMS = number of survey teams

TRAINN = training cost (won/team)

EQN = equipment cost (won/team)

PMNT = % maintenance expense.

The survey costs are for travel expenses, personnel salaries and equipment that is not reusable (reporting forms). Equipment costs are included in fixed survey expenses CN_0. Travel time varies between regions, and personnel use varies with the number of needed observations and travel time. These two items are included in the unit sample cost CN_{hj}.

di

"b

pc

ia

su

ac

Co

o

a

s

t

d

r

c

a

(

(

(

Consumption and Private Storage Surveillance Costs

Much of the framework has been built in the previous section for discussion of food consumption and rural private storage costs. The "base" town observation teams are avilable for surveillance duty. A possible cost minimization routine is available. And background material on Bangladesh is known. The remaining task is to examine possible surveillance techniques and determine if Equations 5.25-5.26 can be adopted.

Consumption Surveys

Common methods for assessing food intake are divided on the basis of purpose of the sampling. The distinct uses are for obtaining group averages versus individual screenings. Assessment of individual consumption is generally done either on the basis of an interview to determine intake in the last twenty-four hours or by a three-to-seven day observation of a household's actual consumption. The methods are referred to as recall and observation, respectively.

Determination of group average consumption levels involves the use of several pieces of information. Some individual sampling is done, and food "disappearance" estimates and family food patterns are used (67). Advantages of the group survey are smaller required time, cost, cooperation, and degree of precision. The twenty-four hour recall method of individual sampling is most efficient for group average use.

In computing consumption levels during a food crisis, several pieces of data will be available apart from the surveillance function. Harvest and storage estimates will tell the total food amount that has "disappeared" through consumption, sales, gifts to poor relatives, or

ho
ti
qu
ho

to
is
cl
no
ca
si
la
mu
Ev
wo
cl

wi
ha
th
in
sm
an
en
cr
Th
ta

hoarding. Reports from feeding programs will indicate food distribution to a sizeable portion of the population. The main data item required of consumption surveillance is an estimate of individual (or household) intake.

A typical recall interview in a developed country may take twenty to twenty-five minutes and cover a wide range of food items (42). This is too long and too detailed a process for famine relief work. Simple, clearly defined questionnaires are needed that can be administered by non-technical personnel. Foods can be classified in three or four categories to reduce the amount of paperwork and statistical processing (64). Such categorization would be especially applicable in Bangladesh where at least two-thirds of the daily diet consists of rice and much of the remaining intake is in the form of curries and pulses (50). Even with short questionnaires, it is doubtful that consumption surveys would be practical during a famine. Consumption sampling will be included in the current study for demonstration purposes.

It will be assumed here that surveillance for consumption levels will take place using a short questionnaire. The survey teams will have the same coverage areas as the nutritional observation teams of the previous section and will consist of the same personnel. Since the interviews are expected to be short and travel requirements are again small, delay time due to measurement requirements is assumed negligible and the cost function form of Equation 5.19 will be used. One difference between QUAC stick measurements and food intake interviews is crucial. The interview techniques will require extensive training. The skill of the observer is the most important consideration in obtaining accurate results (18).

Pr

co

ap

ha

le

me

any

pl

of

For

sto

Cha

meas

Equa

clas

thos

unit

regi

stan

As d

perc

niza

disc

Private Storage

Before examining the specific form of consumption surveillance costs, rural private storage surveillance is discussed. Storage can be approximated by deducting estimated consumed amounts from the estimated harvest. A more accurate method would be to measure actual storage levels by "eyeballing" or more sophisticated techniques. Probably both methods will be needed to assess the degree of hoarding present. In any event, the grain stores will probably be held by households. Sampling of individual household stocks should be quick since the amount of grain involved will be small.

More detailed observation methods must be determined elsewhere. For the current study, it is assumed that food consumption and private storage surveillance will be conducted separately. As a result of Chapter IV findings, only the holdings of the rural class will be measured.

Equation Formats

Assumptions will be made concerning statistical strata, population classes, per unit costs, and standard errors that are very similar to those made for nutritional surveillance. The standard error and per unit costs vary by class and by region. Population proportions vary by region only. The only major difference concerns the use of measurement standard errors SDRC and SDRS for consumption and storage respectively. As discussed in Chapter III, the model assumes that these errors are percentages of the true consumption and storage levels. The cost minimization of Equation 5.22 treats the variance as a true variance. This discrepancy is easily resolved. Observation of model outputs indicates avera

dard

ing l

5.28

wher

are

(CF

inc

and

tio

ful

CS

wh

average values for consumption and storage. The model percentage standard deviations are converted to true standard deviations by multiplying by the average values. The computation is indicated in Equation 5.28.

$$SDT_i = SDP_i * VAVG_i \tag{5.28}$$

where:

SDT = true standard deviation

SDP = percent standard deviation

VAVG = average variable value

i = index on variable (consumption, rural private storage).

Costs for food consumption and rural private storage surveillance are now given in Equations 5.29-5.32. Again, fixed surveillance costs (CFIX) cover training and durable equipment; fixed survey costs (C_0) include replaced equipment; unit sample expenses (C_{hj}) are for travel and salaries. In computing unit sample costs both here and for nutritional surveillance, it is assumed that survey team members have gainful employment in non-survey times. The cost parameters CC, CN, and CS cover one survey day for each team.

$$CSC(TF,SDRC,SMPRC) = CFIX + TF * CSURC(SDRC)/SMPRC \tag{5.29}$$

$$CSS(TF,SDRS,SMPRS) = CFIXS + TF * CSURS(SDRS)/SMPRS \tag{5.30}$$

$$CSURC(SDRC) = CC_0 + \frac{1}{SDRC^2} * \sum_{j=1}^{4} \left(\sum_{h=1}^{4} W_h SC_j \sqrt{CC_{hj}} \right)^2 \tag{5.31}$$

$$CSURS(SDRS) = CS_0 + \frac{1}{SDRS^2} * \left(\sum_{h=1}^{4} W_h SS \sqrt{CS_h} \right)^2 \tag{5.32}$$

where:

Tr

mi

fi

fi

CSC = consumption surveillance cost (won)

CSS = storage surveillance cost (won)

SDRC = consumption measurement standard error

SDRS = storage measurement standard error

SMPRC = consumption sampling interval (years/survey)

SMPRS = storage sampling interval (years/survey)

TF = time duration of emergency (years)

CSURC = consumption survey cost (won/survey)

CSURS = storage survey cost (won/survey)

W_h = population proportion, stratum h

SC = consumption standard error of population

SS = storage standard error of population

CFIXC = consumption fixed surveillance cost (won)

CFIXS = storage fixed surveillance cost (won)

CC_0 = consumption fixed survey cost (won/survey)

CS_0 = storage fixed survey cost (won/survey)

CC = consumption unit sample cost (won/sample)

CS = storage unit sample cost (won/sample)

h = index on strata

j = index on population class.

Transmission and Processing Costs

Previous simplifying assumptions have made the cost of data transmission the main link to the delay parameter of $\underline{X}$. Transmission is defined here as whatever methods are used to transform (and process) the field-acquired measurements into reports usable by system managers.

is

reg

eac

gio

tha

bee

ex

ti

si

tr

ti

al

Da

to

st

De

a

w

f

s

a

v

The extant communication network in Bangladesh discussed earlier is a logical starting point. Efficient microwave channels connect the regional centers to the capital, Dacca. Five or six small towns in each of the four regions serve as "bases." These are linked to the regional center by an old and inefficient UHF network. Other facilities that may be useful include several mobile UHF base units which have been used for emergency work, primarily during floods. Telephones exist only in the largest cities and are not reliable.

Surveillance procedures previously discussed call for one observation team's operating out of each base town. We will assume that the single team can handle the three types of surveillance. Thus, the transmission process involves team reports to the base town, where initial processing takes place; UHF or other communication with the regional centers; and additional processing and microwave transmission to Dacca, where final reports are prepared. Messenger service from base towns to regional centers may be required, depending on the UHF network status.

Delay Parameter DELD

The delay parameter, DELD, from the survival model represents the average amount of time needed to complete the above process. It may well be that urgent messages can be sent very quickly, but the desired figure here is the normal time needed over the course of the food crisis. Costs include personnel training, salaries, equipment purchase, and maintenance.

For the purposes of this study, the existing system in Bangladesh will be considered the overall minimum cost, maximum delay alternative.

Reductions in the average delay time will require improvements to the current structure. The cost function will be constructed by citing three feasible system additions in order of priority. Costs and delay time improvements will be estimated for each addition. Then, four points on the cost function curve will be calculated by successive additions to the basic system. The functional shape is indicated in Figure 5.1. Linear interpolation will be used to estimate costs for delay times among the four designated alternatives. This allows generation of a transmission cost for any delay level DEL within parameter constraints. Note that the costs are additive; alternative III includes the cost of alternatives I and II, etc. The monetary conversion rate used here is four hundred won equal one dollar. It should be noted that the won is the monetary base in Korea, the country modeled in the original simulation (38). The takka is the currency base for Bangladesh.

System Additions and Costs

As mentioned, the first alternative is the existing system, including the microwave and UHF network and the personnel and equipment needed to operate the base stations. It is also assumed that a high level computer is available at Dacca for computation, analysis work, and storage. This base alternative is point number I in Figure 5.1.

The first addition to the basic system (point II in Figure 5.1) is a set of two-way transceivers for each base, observation team, and regional center. These radios would allow rapid reporting to the base so that processing is not delayed while teams return from surveillance. The transceivers would also be a back-up for the UHF system. Some

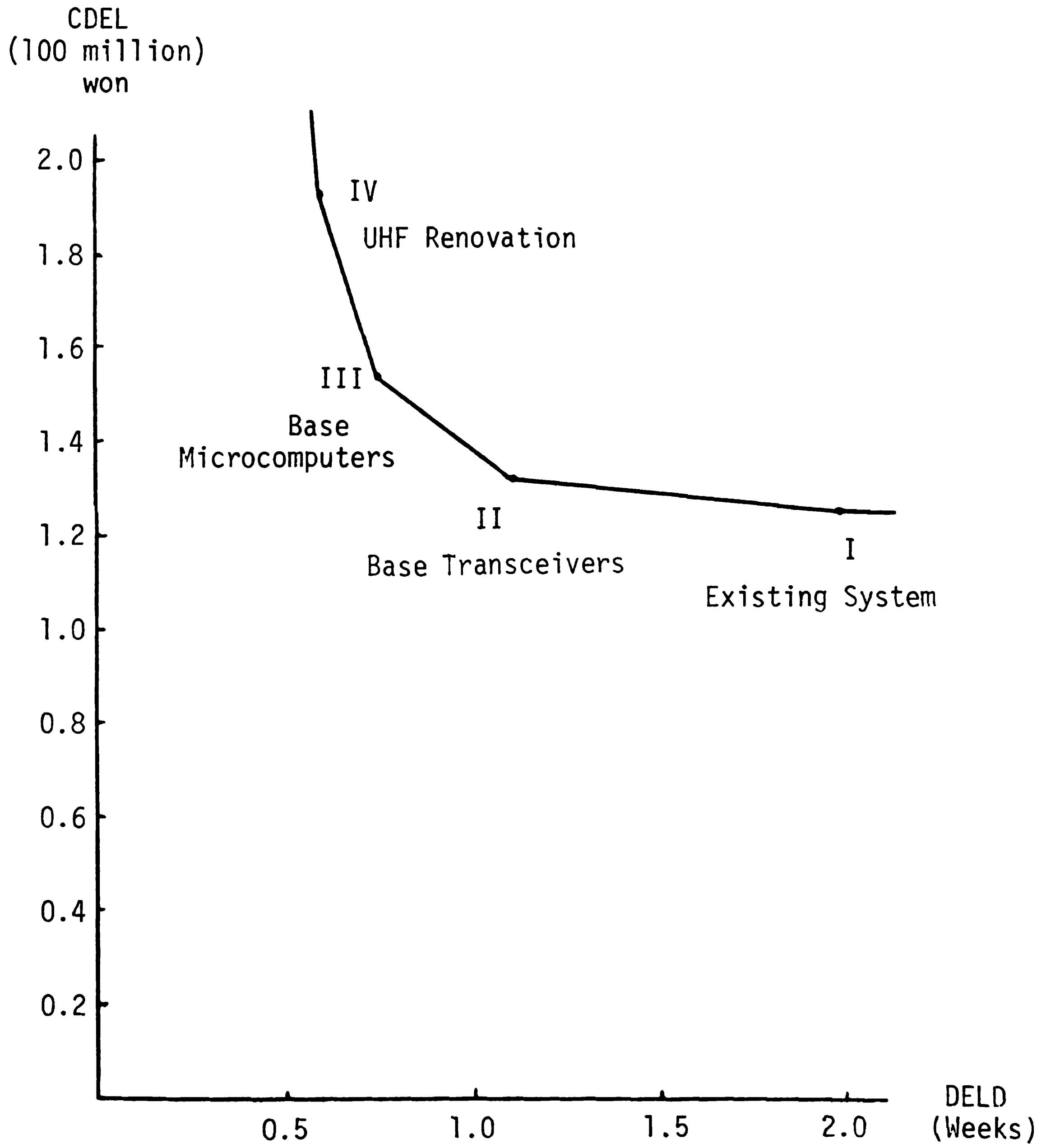


Figure 5.1. Transmission and Processing Cost as a Function of Information Delay.

effort has been expended on the design and construction of radios that are inexpensive, reliable, and able to transmit and receive over fairly long distances (65). The resulting unit reportedly has a broadcast range of 160 miles and costs approximately one hundred dollars. The predicted range should cover each surveillance area and most base-town-to-regional-center links.

The next suggested improvement (in addition to radios) is a microcomputer to speed the processing task at base locations. The computational power needed at the base level consists mainly of means and standard errors from survey results. A programmable calculator with printer should provide the necessary power and a hard copy for error checks. Additional personnel are assumed to be needed for operation of the new computers.

The last improvement considered is the renovation of the UHF network. This would be advantageous for many purposes beyond famine relief.

Costs for each of the above improvements are assigned to the famine relief information system based on estimated purchase price, maintenance expense, depreciation percentage, usage level for famine relief, yearly salaries, duration of the emergency, and number of equipment and personnel units required. This breakdown of cost components is helpful in assigning total cost. The breakdown also allows analysis, using sensitivity tests to indicate critical cost considerations.

Equipment costs are computed for each alternative using the form of Equation 5.33. This applies to the initial equipment, microwave, UHF, radios, and calculators. The number of units times the price per unit gives the base cost. Percentage maintenance and depreciation are facto

assig

will

main

where

expe

clud

by t

othe

flec

wher

factored in, as well as a usage proportion, to arrive at a yearly cost assignable to famine relief. Maintenance and depreciation factors will be high in Bangladesh due to high humidity, theft, and few trained maintenance people.

$$CEQ_i = UEQ_i * WEQ_i * (MAINT_i + PDEP_i) * PUS_i \quad (5.33)$$

where:

CEQ = equipment cost (won/year)

UEQ = units of equipment

WEQ = equipment purchase price (won/unit)

MAINT = percent maintenance cost

PDEP = percent depreciation

PUS = percent equipment usage for relief

i = index on equipment items.

Equation 5.34 contains the form used for calculating personnel expenses for transmission of famine relief data. Two costs are included, for salaries and training. Per person costs are multiplied by the number of personnel. Because the operators may work on projects other than the relief effort, a parameter (PRPUS) is included to reflect percentage time spent on relief.

$$CPR_j = UPR_j * (WPR_j + TPR_j) * PRPUS_j \quad (5.34)$$

where:

CPR = personnel cost (won/year)

UPR = number of personnel (persons)

WPR = salary (won/person-year)

TPR = training cost (won/person-year)

and
very
avai

for
to
The
cos
len
ge

wh

s
f
p
s

PRPUS = percent personnel time for relief

j = index on personnel type.

The exact parameter values used are in the tables of Appendix A and in the FORTRAN code in Appendix B. Estimation of the parameters is very crude since little exact cost information from Bangladesh is available.

The information quality parameter DELD is the independent variable for function CDEL of Figure 5.1. The value obtained is the yearly cost to provide information transmission with the given average delay time. The relief information system expense is computed by multiplying yearly cost by the length of the food crisis, as in Equation 5.35. Emergency length is easily obtainable in the model by observing the crisis trigger described in Equations 2.11.

$$CDELF(DELD,TF) = CDEL(DELD) * TF \qquad (5.35)$$

where:

CDELF = food crisis transmission cost (won)

CDEL = yearly transmission cost (won/year)

TF = length of crisis (years)

DELD = information delay parameter.

Summary

The surveillance and transmission cost equations of the last three sections are cast in a form where they are solved once for a given information quality vector and simulation run. This corresponds to proposed calculation of the cost function in an analysis off-line from the survival model performance function. Cost parameters then represent ave

cos

add

whe

cum

spe

des

to

on

average figures over the crisis duration. The total information system cost in this modeled off-line analysis is obtained in Equation 5.36 by adding the transmission and surveillance costs.

$$G(\underline{X}) = CDELF(DELD,TF) + CSN(TF,SDND,SAMPT) + CSC(TF,SDRC,SMPRC) + CSS(TF,SDRS,SMPRS) \quad (5.36)$$

where:

G = information system cost (won)

$\underline{X}$ = information quality parameter

DELD = information delay (years)

SDND = nutritional debt measurement error

SDRC = consumption measurement error

SDRS = private storage measurement error

SAMPT = nutritional debt sampling interval

SMPRC = consumption sampling interval

SMPRS = private storage sampling interval

CDELF = transmission and processing cost (won)

CSN = nutritional surveillance cost (won)

CSC = consumption surveillance cost (won)

CSS = storage surveillance cost (won)

TF = food crisis duration (years).

An alternative cost modeling procedure would be to dynamically accumulate costs as the simulation proceeds. Costs would be assigned to specific events, such as sampling, transportation, etc. Each time the designated events occur, a cost would be generated (perhaps randomly) to augment the expense total. Note that this would require more detail on the separate components of system alternatives than the current model provides. Co

dology is an

The func

odology by i

discusses the

mation quali

the G functi

function com

As disc

monetary con

requirements

ment and per

approach to

available si

here. This

tion.

provides. Comparison of this modified approach with the current methodology is an area of possible further research.

The function G($\underline{X}$) provides an important link in the proposed methodology by identifying the cost of information quality. This chapter discusses the relationships among system alternatives, costs, and information quality parameters; it also describes needed characteristics of the G function. Several examples are given of the development of cost function components.

As discussed in Chapter IV, the only "cost" considered here is the monetary constraint on information quality. Equipment and personnel requirements are converted to monetary units. It may be that the equipment and personnel limitations require their own "cost" functions. An approach to generating personnel and equipment functions should be available similar to the monetary cost function development described here. This whole constraint and costs area deserves much more attention.

the s

ing a

pose

of th

to be

infor

provi

The w

polic

prese

to pr

ageme

This

nutri

cesse

CHAPTER VI

INFORMATION FILTERS FOR SYSTEM MANAGEMENT

This chapter examines the famine relief information system from the systems' manager's perspective. Chapter V describes a data gathering and transmission process as it might occur in Bangladesh. The purpose there is to identify the costs involved in surveillance. The role of the decision maker is avoided because management expenses are felt to be a part of the overall relief effort rather than assignable to the information system. In Chapter III a sampling component is modeled, providing information of set precision levels to the system managers. The work of these decision makers is simulated by a series of fixed policy rules. The rules assume a constancy of reaction that is not present in real situations. So the purpose of the current chapter is to provide a more realistic view of the use of information by the management group.

A recent symposium on famine relief operations recommends that:

> ...a headquarters analysis group should be organized including experts in management, health, nutrition, agriculture, and social sciences to collate, interpret the significance and relationships of all information, determine trends, develop priorities, and predict future developments (7, Recommendations).

This broad charge is echoed by a World Health Organization monograph on nutritional surveillance, which states that system managers need processed data enabling them to describe contemporary conditions,

identi
the si
M
curren
and go
on wat
also b
as num
_A_
storag
crease
vary r
prior
and s
mine.
sponso
sions
mon u

polic
polic
model
devis
forma
used
scrib

identify trends, predict changes, and elucidate underlying causes of the situation (25).

Many bits and pieces of information will be used by managers. The current model requires data on nutritional level, consumption, private and government food stores, and population levels. Additional reports on water and disease levels, transportation availability, etc., will also be needed. Sample surveys will likely include narrative as well as numerical portions.

A priori knowledge will enter into decision making. For example, storage levels should decrease until the harvest and then should increase dramatically. Some variables, such as consumption, are known to vary more rapidly than others. It was mentioned in Chapter V that a priori harvest information can be used along with estimates of sales and storage to approximate average consumption levels.

The urgency of decision making changes during the course of a famine. Reports of new instances of dire shortages call for quick response. Unexpected occurrences can alter plans and vary timing decisions. War, natural disaster, or additional international aid are common unexpected occurrences.

Thus, the decision process involves much more than a series of policy rules. The survival model of this thesis employs the general policy rules for three reasons. First, the hypothetical country being modeled does not have an explicit policy structure; each country must devise its own. Second, this model represents the first stages of information system development. It is hoped that this approach can be used to step beyond the current model. Finally, because the model describes processes at a macro level, the policies are constructed as

aver
gent
smoo

sugg
vary
the
woul
numb
the
out
comp
incr
Chap

the
sire
is d
esti
lay.
whil
chan
The
form
filt
tota
chap

average expected decisions. It is assumed that the fluctuation in urgent data needs, available reports, and unexpected occurrences will smooth out over the several months' duration of the crisis.

The variety of actual information sources and timing requirements suggest two additions needed in a more complete survival model: time-varying parameters and information filters and predictors. Allowing the model policy and information quality parameters to vary with time would provide the flexibility needed to simulate response to a great number of scenarios. The disaster type could be better tailored to the particular region of application. But this capability is not without a price. Strategy construction and optimization work are greatly complicated as the number of parameters mushrooms. The parameter total increases multiplicatively with the number of changes allowed (27, Chapter 3).

Filters and predictors can be easily added to the model. Recall the sampling component of Chapter III. The "true" time series for desired variables is estimated at specified survey times. This estimate is delayed and then used in the policy rules. Between surveys, the estimate remains constant; it is a sample-and-hold, or zero-order, delay. A filter would affect the estimation process at the survey times, while a predictor would allow changed estimates between surveys. These changes are easily implemented, both in the model and in the real world. The basic question to be answered is whether such techniques can perform better than the simple sample-and-hold estimator. That is, can a filter or predictor sufficiently augment information quality so that total deaths and total nutritional debt are lowered? The rest of this chapter is a step toward the answer. The Kalman filter and the so-

add

mat

str

are

fro

res

pro

in

ch

cu

sa

ar

bu

th

la

th

di

pl

be

sa

di

so-called alpha-beta tracker are briefly described, then the tracker is added to the survival model and performance tests are conducted.

Filters and Predictors

Any estimator represents an attempt to get the most possible information from a set of captured data. The data processing, population stratification, and sample size determination mentioned in Chapter V are all part of a sample methodology aimed at extracting maximum worth from surveillance work. The inputs to sample estimators would be the results from one survey.

Filters and predictors add a dynamic dimension to the estimation problem. The process under study is changing with time, and desired information includes not only absolute levels, but the nature of the changes. A filter commonly uses all previously known data as well as current survey results to make an estimate. This is distinct from the sample-and-hold technique of Chapter III, where current survey results are used exclusively. The predictor also employs past and current data, but projects the trends to estimate future results. The hope is that these tools can increase information quality without additional surveillance or transmission costs. Testing a filter also provides clues on the system performance effects of auto-correlated information.

In this section we examine two filters and their associated predictors. The alpha-beta (α-β) tracker is commonly used in radar applications to track positions and direction of aircraft. Alpha and beta refer to parameters of the filter. The tracker is added to the sampling component and tested in the next section. The second filter discussed is the so-called Kalman filter. This appears to be an exce

here

piec

pred

data

of t

func

(11,

wher

Chap

Chap

cycl

tere

Y(T)

excellent filter alternative in real applications. It is not tested here because its structure is not practical in the current context.

The implementation of an α-β tracker is quite simple. Each new piece of information serves as an input to a set of three equations. A predicted function value is computed based on past information. The new data and the predicted value are combined to form a "smoothed" estimate of the current situation. The rate of change, or velocity, of the function is also estimated. The set of equations is presented here (11, Chapter 8.11).

$$Y_p(T) = Y\,(T\text{-}SAMP) + SAMP * Y_d(T\text{-}SAMP) \quad (6.1)$$

$$Y\,(T) = Y_p(T) + \alpha * (u(T) - Y_p(T)) \quad (6.2)$$

$$Y_d(T) = Y_d(T\text{-}SAMP) + \beta * u(T) - Y_p(T) \,/\, SAMP \quad (6.3)$$

where:

Y_p = value predicted from past information

Y = smoothed value used as estimate

Y_d = function velocity estimate

u = survey result

SAMP = sampling interval (years)

T = current time

α,β = parameters of filter.

Note how this tracker compares to the sample-and-hold scheme of Chapter III. HOLD(T) equal to u(T) is the output of routine SAMPL in Chapter III and HOLD(T) is sent to the delay VDTDLI at each simulation cycle DT for one complete sampling interval (DT<<SAMP). One very interesting fact can be seen in Equation 6.2. If α has value one, then Y(T) equals u(T), and we have the sampling procedure of Chapter III.

Eq

samplin

dictor

tween c

6.4, a

dicted

Y

where:

T

T

Y

A

(11, (

impor

cally

and 6

time

quick

equa

u(T)

is n

the

Equations 6.1-6.3 form a filter; a new estimate is obtained at each sampling point. A modification of Equation 6.1 can be used as a predictor between surveys. Replacing SAMP with the differences $(T-T')$ between current time and the time of the past survey produces Equation 6.4, a familiar linear extrapolation equation. The function is predicted to be moving in the direction indicated by rate of change Y_d.

$$Y_p(T) = Y(T') + (T-T') * Y_d(T') \qquad (6.4)$$

where:

T = current time

T' = time of last sampling point

Y_p, Y, Y_d = as in Equations 6.1-6.3.

An analysis of α-β tracker characteristics is presented by Cadzow (11, Chapter 8). Three considerations make the selection of α and β an important part of filter design. First, to insure stability, a critically damped response will require that α and β satisfy equations 6.5 and 6.6.

$$\alpha = 2\sqrt{\beta} - \beta \quad \text{(critical damping)} \qquad (6.5)$$

$$0 \leq \beta \leq 4 \quad \text{(system stability)} \qquad (6.6)$$

The other two parameter considerations are for system response time and measurement error suppression. Values of β close to one cause quick response to new information. This is easily seen, for when β equals one, α is also one, according to Equation 6.5. Then $Y(T)$ equals $u(T)$, as discussed earlier. To supress error, a value of β near zero is needed. Thus, the normal parameter selection process limits β to the region between zero and one. β is chosen according to response and error s

6.5.

If

error

α-β t

class

tion i

T

cussed

crete-

where

and

6.8.

on a

tion

error suppression requirements, and α is then computed using Equation 6.5.

It is worth noting here that the α-β tracker has important minimum error properties. For a given noise smoothing performance index, the α-β tracker is optimum for both position and velocity tracking in the class of all fixed parameter linear tracking equations given the relation in Equation 6.7 (5).

$$\beta = \frac{\alpha^2}{2 - \alpha} \tag{6.7}$$

The Kalman filter is more complex than the α-β tracker. As discussed by Schweppe (56, Chapter 6), the filter requires a discrete-time linear system model of the form of Equations 6.8.

$$\underline{x}(n + 1) = \underline{F}(n)\, \underline{x}(n) + \underline{G}(n)\, \underline{w}(n) \tag{6.8a}$$

$$\underline{Z}(n) = \underline{H}(n)\, \underline{x}(n) + \underline{v}(n) \tag{6.8b}$$

where:

$\underline{x}$ = state variable vector

$\underline{Z}$ = observation vector

$\underline{F},\underline{G},\underline{H}$ = known system descriptive matrices

$\underline{w},\underline{v}$ = error vectors

n = time.

Estimated variables would be members of the $\underline{x}$ vector. The filter and predictor are constructed from the matrices and vectors in Equations 6.8. All estimates would be derived in one matrix process and are based on a priori knowledge of the system as well as past and present observations. This is distinct from the α-β tracker, where a separate filter is n

cons

that

matc

the

tem

deb

nut

Ka

An

su

of

wo

c

s

w

t

is needed for each variable and variable interactins are not explicitly considered. The Kalman filter is the "best" linear filter in the sense that it yields the minimum error covariance matrix of any linear estimator (56, Chapter 6.3.9).

Additional research must be done to determine the applicability of the Kalman filter to famine relief information. The overall relief system, as modeled here, is highly nonlinear. For example, nutritional debt is a complex function of consumption, required nutrition and past nutritional levels (see Equations 2.1, 2.2). The system model $\underline{F}$ for the Kalman filter would have to be linearized on a constrained variable set. Another possible pitfall is the relative lack of information. Sample surveys can provide data weekly, at best. It may be that this is not often enough for the filter to perform efficiently. Unfortunately, it would be an unfair test to evaluate the Kalman filter in the current context. Testing Kalman would involve the use of linear model of the survival model within the survival model. The linear estimator model would be patterned after the nonlinear survival simulation, so that the two would reinforce possible inaccuracies.

Testing the Alpha-Beta Tracker

Several questions are of interest with regards to any information filter. The main question that system planners will be concerned with is whether or not the filter (or predictor) can improve information reliability and relief performance over the basic sample-and-hold estimation process. Once the filter is determined to be useful, parameter or matrix coefficient levels for fine tuning must be considered. The variables to be filtered must be selected. And it must be determined whether

choice.

sign is

Tr

tracker

sample-

perfor

differ

the le

final

of Eq

quest

and i

β va

secon

iabl

plac

tera

ied

miz

mak

sul

ter

fi

no

whether information quality makes a difference in parameter level choice. The range of problems to be examined indicate that filter design is a complex subject.

Translating the above questions to the specific case of the tracker focuses study on the β parameter. β equals one represents the sample-and-hold case. Does a β value less than one provide superior performance? What value of β is "best"? Does the level of "best" β differ between filtered variables? Between population classes? Does the level of information quality vector $\underline{X}$ affect the choice of β ? One final alternative to study is whether the use of the linear predictor of Equation 6.4 will improve performance.

There are at least two alternative methods for answering these questions within the current framework. First the survival model policy and information parameters can be held constant as the tracker parameter β varies. This allows study of the filter performance alone. The second alternative would be to provide trackers for several of the variables and classes, give each tracker a separate β parameter, and place all parameters into the optimization portions of the study. Interactions with policy and information parameters are more easily studied and "best" β values can be obtained with this alternative.

Neither method is a unanimous choice for tracker study. The optimization alternative will give "best" values, but only if the tracker makes a difference on performance. Strict adherence to numerical results could indicate a specific β be implemented when in truth no filter should be used. Examining the tracker with all other components fixed can indicate its worth but does not reveal "best" values because no dynamic interactions are present.

A

altern

worthw

be inc

Thus,

model

linea

The c

comp

Cert

is i

cont

debt

duce

lea

mod

Bot

ter

err

Eva

A

ti

gi

al

A prudent approach is to take advantage of the good points of both alternatives. The first step would be to determine if the tracker is worthwhile, using the fixed method. Then filters that show promise can be included later in optimization work, to determine "best" values. Thus, in this section, the α-β tracker is studied with the rest of the model fixed. The questions of variables to be filtered, the use of the linear predictor, and the worth of the tracker itself are examined here. The choice of "best" β values is studied in Part II.

Before discussing the details of adding the tracker to the sampling component, the definition of "best" in the above paragraph is examined. Certainly, the bottom line in determining "best" performance of a filter is its ability to positively influence system outputs. In the current context, this means reduction of total deaths and total nutritional debt. A secondary criterion would be the ability of the filter to reduce measurement error. This improvement in information quality will lead to better system outputs, if the policy structure is sound. The modeler has a unique opportunity to assess measurement error reduction. Both the true and estimated variable time series are known in a computer simulation. Thus, a measure of the mean squared error or absolute error can be readily calculated.

Evaluation Tools

Three evaluation tools are used here to check tracker performance. A mean squared error figure is computed, comparing true and estimated time series for a specific β level. The form of this calculation is given in Equation 6.9. For each β value tested, an absolute figure is also computed, using Equation 6.10. As β changes, the error figures are (

like

where

the

in m

fluc

prov

Chap

mode

num

is

βv

dev

Cha

var

are observed. Significant reduction in error is regarded as a sign of likely improved performance.

$$MSE_{Vi} = \sum_{j=1}^{n} (V_{ij} - \hat{V}_{ij})^2/n \qquad (6.9)$$

$$ABSE_{Vi} = \sum_{j=1}^{n} V_{ij} - \hat{V}_{ij} \qquad (6.10)$$

where

MSE = mean squared error

ABSE = absolute error

V = true value of filtered variable

$\hat{V}$ = filtered value of variable

n = number of discrete intervals in simulation

i = index on variables

j = index on simulation intervals.

Because there are stochastic equations in the survival model and the sampling component, it is not immediately known whether differences in measured error are due to tracker parameter changes or to random fluctuations. So as a second tool, a statistical t-test is employed to provide evidence on the tracker's ability to reduce error. Recall from Chapter III that the survival model can be operated in a Monte Carlo mode, computing sample means and standard deviations for a specified number of simulation replications. The hypothesis test to be conducted is to check whether the means of Monte Carlo runs with distinct tracker β values are statistically different. The sample means and standard deviations are the needed statistics for the two-sample t-test (61, Chapter 9). A complication arises in using this test if the sample variances are not equal (61, Chapter 13). Fortunately, the problem is avoic

tions

equa

comp

wher

for

mor

err

dea

th

th

re

th

co

de

de

A

C

avoided if the number of observations (number of simulation replications) is the same for each sample. Thus, all testing is done with equal replications for each different β value, and the t-statistics are computed as in Equation 6.11.

$$t = (\overline{Y}_1 - \overline{Y}_2) / \sqrt{\frac{1}{n}(s_1^2 + s_2^2)} \qquad (6.11)$$

where:

- t = t-statistic
- $\overline{Y}_1, \overline{Y}_2$ = sample means
- s_1, s_2 = sample standard deviations
- n = number of replications

A third evaluation of tracker performance is used, based on the information desired by decision makers. Planners and managers will be more interested in improvements in system outputs than in statistical error reduction. For each replication in the Monte Carlo runs, total death and total nutritional debt are recorded. Then, each replicate in the filter alternative (β <1.0) is compared to the average figure for the basic sample-and-hold component (β =1.0). The fraction of improved replicates to total replicates provides an estimate of the probability that the tracker will improve performance. This is, each replicate is considered a possible outcome, and reduction in deaths or nutritional debt a success. Note that separate probabilities will be recorded for deaths and for nutritional debt.

Adding the Tracker to the Model

The α-β tracker is very easily added to the sampling component of Chapter III. Recall that the term EST in Equations 3.4 and 3.5

repre

is th

ceive

rout

beco

(Y)

tor,

so t

off

Tes

rol

cor

ter

an

tr

wi

ne

Th

ca

n

a

m

m

l

represents the sampled variable value before delay is introduced. EST_k is then an input to the routine VDTDLI, whose output is the estimate received by decision makers. The filter does not at all change the delay routine. An additional stage is added between sampling and delay. EST_k becomes the input to the filter (u in Equation 6.2). The filter output (Y) becomes the new input to VDTDLI. In the case of the linear predictor, Y_p is the input to VDTDLI. Equation 6.5 is included in the model so that β is the only parameter to be specified. The tracker is turned off by setting β equal to one, as discussed earlier.

Testing by Sampled Variable

A series of tests is now described whose goal is to determine the role of the α-β tracker in the current study. The tests do not provide conclusive evidence about the worth of the tracker in information system work, but they do indicate the path to follow here.

The primary questions to be addressed are which variables to filter and which filter parameters to include in later optimization. The tradeoff is common. Including too many parameters in the optimization will complicate the process and the solution. But the exclusion of needed parameters can obscure model or information system structure. There are nine variables that are candidates for filtering. Four per-capita nutritional debt and four per-capita consumption variables are needed to describe the population groups. And one rural private storage figure completes the total. These are the variables covered by the modeling sampling routine, as discussed in Chapter IV. Thus, the maximum number of parameters that could be added to the optimization would be nine. The minimum would be zero.

for

ple

ence

dist

shou

β va

deat

tat

ure

it

gio

the

by

ur

fi

Co

er

bu

ag

n

S

t

i

The first sensitivity test involves the use of identical β values for each of the nine filters. The predictor is not employed. This simple test is aimed at discovering whether the tracker makes any difference in measurement error or system performance. Identical β values can distort performance effects, but error reduction with tracker usage should be clear. Five Monte Carlo replications are done at each of four β values and the results (absolute error, mean squared error, total deaths, total nutritional debt) are presented in Table 6.1. A representative class has been chosen for nutritional debt and consumption figures. The urban poor class with no rural relatives is listed because it is the one most affected by the relief policy.

Note that the β values in Table 6.1 cover the (0,1) stability region. As discussed earlier, sample means and standard deviations for the Monte Carlo replications are given. Randomness has been introduced by a fixed "good" information vector $\underline{X}$.

Low error means, low death totals, and small nutritional debt figures are regarded as good in reading the table. So nutritional debt is filtered best for β equal 0.7 or 0.1, according to the error measures. Consumption filtering is best at the end points. Note that absolute error and mean squared error do not correspond exactly for all changes but do agree on relative sizes for large error differences. The disagreements for close values are probably caused by random fluctuations.

The significance of the changed error measures with changing β for nutritional debt and consumption filters is examined in Table 6.2. Storage is not included, as the filter provides worse performance. A t-statistic, as computed in Equation 6.11, is presented. The hypothesis is that the sample means for β equal 0.1 are improved over the means at

Table 6.1. Error Means and Standard Deviations with the

Table 6.1. Error Means and Standard Deviations with the α-β Tracker for Five Monte Carlo Replications at Various β Values.

	Absolute Error Equation 6.9 (Standard Deviation)			Mean Squared Error Equation 6.8 (Standard Deviation)			Performance (Standard Deviation)	
	Nutritional Debt	Consumption	Storage	Nutritional Debt	Consumption	Storage	Deaths (Millions)	Total Nutritional Debt (1000 MT)
β=1.0	1.178 (.2056)	20.55 (3.65)	.9565E8 (.317E7)	.425E-5 (.420E-5)	.302E-2 (.143E-2)	.962E11 (.510E10)	3.43 (.360)	47.34 (11.8)
β=0.7	1.057 (.113)	23.06 (5.27)	.944E8 (.319E7)	.653E-5 (.141E-5)	.397E-2 (.222E-2)	.102E11 (.323E10)	3.53 (.279)	34.77 (10.3)
β=0.4	1.255 (.148)	23.51 (2.64)	.114E9 (.726E7)	.951E-5 (.162E-5)	.379E-2 (.622E-3)	.121E12 (.528E11)	3.49 (.305)	49.0 (31.7)
β=0.1	1.024 (.288)	14.09 (3.24)	.144E9 (.765E7)	.677E-5 (.275E-5)	.149E-2 (.590E-3)	.174E12 (.947E10)	3.36 (.550)	80.9 (19.3)

St

Sigr
L
(

β e

est

ter

ity

dif

ly

fi

sq

6.

ac

al

re

f

a

p

Table 6.2. T-Statistics and Acceptance Levels for Hypothesis Tests on Means of Table 6.1, β=1.0 versus β=0.1.

	Absolute Error		Mean Squared Error	
	Nutritional Debt	Consumption	Nutritional Debt	Consumption
t Statistic	.473	2.459	1.105	2.219
Significance Level (ν=4)	.25	.025	.25	.05

β equal 1.0. The 0.1 β level was chosen as generally giving the smallest mean, and, of course, the 1.0 level represents the case of no filter. The significance level in the table is the approximate probability that an error will be made in assuming the compared means to be different. A one-tailed test is used with four degrees of freedom.

Statistically, the per-capita consumption filter is much more likely to cause error reduction than is the per-capita nutritional debt filter. Table 6.2 shows that both filters may reduce absolute or mean squared error. But performance, as measured by total deaths in Table 6.1, is unaffected. The mean total nutritional debt figures vary widely across β values. It should be noted, however, that nutritional debt also has large standard errors for a given β . Total deaths is a more reliable performance figure and shows little change with β .

The inconsistency of reduced error and static performance bears further attention. A second test with distinct β values by variable and by class will be conducted. First, however, the case of the rural private storage filter in Table 6.1 will be examined. It is clear from the RS

the de

consu

can b

iable

of a

time

call

is a

true

inte

the

esti

addi

Equa

cha

whe

th

the RSTOR columns that error increases as β decreases. It may be that the degrading storage information has offset the improved nutrition and consumption data and left the performance statistics unchanged. This can be checked with distinct β values in the upcoming test.

It appears that the α-β tracker does not estimate the storage variable well. One further filter modification was explored, making use of *a priori* knowledge of the expected behavior of the private storage time series. The rural private storage level should decrease monotonically until the harvest. Afterwards, stores oscillate as the new crop is added and then removed for consumption and sales purposes. This is true in the model and would also hold in the real world case where no international aid is forthcoming.

The filter modification involves the long downward slope before the harvest. Equations 6.1-6.3 indicate a predicted value Y_p and the estimate employed, Y. At each sampling point before the harvest, an additional filter step is added to magnify storage estimate decreases. Equation 6.12 is the simple minimization used. The tracker was unchanged for the period after initial harvesting.

$$Y_m(T) = \text{minimum}(Y(T), Y_p(T)) \tag{6.12}$$

where:

Y_m = modified tracker estimate

Y = original tracker estimate

Y_p = predicted value from past information

T = time.

No performance change was noted for the modified filters, even when the storage β was uncoupled from β's for other variables. There was a slight

decreas

these t

is als

result

later

Testin

W

variat

parame

and β

separ

ple-a

tion

this

beyor

debt

And

the

curs

the

squa

This

red

slight improvement in the error terms, but error still worsened as β decreased. It is possible that the policy parameters P being used in these tests do not allow the storage filter to operate efficiently. It is also possible that the tracker does not work well here. Based on the results in Table 6.1, the storage β parameters will not be included in later optimization work; the sample-and-hold estimator will be used.

Testing by Population Class

We now turn to tests involving distinct filters for the separate variables and population classes. From Table 6.1, the most promising parameter values are β equal 0.7 or 0.1 for the nutritional debt filters and β equal 0.1 for consumption. These three cases were simulated separately, and the results are presented in Table 6.3. The base sample-and-hold case is also given, copied from Table 6.1. Note the fraction included in table "performance" entries. As discussed earlier, this is a probability that the given filter causes improved performance beyond the base case.

The two rows in Table 6.3 that represent per-capita nutritional debt filters (β_{NUT}) show no significant change in system performance. And the measured errors are unchanged for β_{NUT} equal 0.7 compared to the base case. The only significant nutritional debt filter change occurs for error terms when β_{NUT} equals 0.1. But the t-statistics, using the five Monte Carlo replications and comparing nutritional debt mean squared error for the base case versus β_{NUT} equal 0.1, is only 1.25. This is significant at the .25 level, similar to results in Table 6.2.

The consumption filter greatly affects system performance. The reduction in total deaths for β_{CON} equal 0.1 is statistically very

Tracker Results with Distinct β Values for Five Monte Carlo Replications.

Table 6.3. α-β Tracker Results with Distinct β Values for Five Monte Carlo Replications.

	Absolute Error Equation 6.9 (Standard Deviation)		Mean Squared Error Equation 6.8 (Standard Deviation)		Performance (Standard Deviation)	
	Nutritional Debt	Consumption	Nutritional Debt	Consumption	Total Deaths (Millions)	Total Nutritional Debt (1000 MT)
$\beta_{NUT}=1.0$	1.178	20.55	.925E-5	.302E-2	3.43	47.34
$\beta_{CONS}=1.0$	(.2056)	(3.56)	(.420E-5)	(.143E-2)	(.36)	(11.8)
$\beta_{NUT}=0.7$	1.79		.426E-5		3.56	47.38
$\beta_{CONS}=1.0$	(.1821)		(.337E-5)		(.54) 1/5	(19.0) 3/5
$\beta_{NUT}=0.1$	.992		.657E-5		3.47	47.68
$\beta_{CONS}=1.0$	(.162)		(.229E-5)		(.33) 2/5	(25.0) 2/5
$\beta_{NUT}=1.0$		23.81		.360E-2	2.734	69.66
$\beta_{CONS}=0.1$		(6.04)		(.167E-2)	(.27) 5/5	(18.0) 0/5

sign

at β

Tota

rela

ror

exam

put

ble

umn

fig

det

exc

eve

ti

la

th

ve

O

m

m

g

e

significant (t=3.5). Just as importantly, each Monte Carlo replication at β_{CON} equal 0.1 produced a lower death total than the base average.* Total nutritional debt increases, as would be expected by its inverse relationship to total deaths. An anomaly is present, however. The error increases when β_{CON} equal 0.1. Additional insight is provided by examining each class separately.

Table 6.4 contains selected filter data by class for the same computer runs presented in Table 6.3. Note the agreement between the tables for the Total Death, Total Nutritional Debt, and the Urban_1 columns. Only mean squared error terms are given, as the absolute error figures show similar results.

Two items are of interest in Table 6.4. Per-capita nutritional debt error is reduced with the use of the α-β tracker for each class except the urban rich. The differences are not highly significant, however. And performance does not change. Conversely, per-capita consumption class filters show little change in error terms but provide a large performance difference.

Neither variable type provides conclusive evidence on the worth of the α-β tracker. The fixed policy parameters $\underline{P}$ and information quality vector $\underline{X}$ may exert an unseen but powerful force on the test results. Or it may be that the model is, indeed, highly sensitive to changes in measured consumption and not sensitive to varying nutrition measurements. Previous work with the model would indicate that the first suggestion is more probably correct than the second.

---

*This is the meaning of the 5/5 fraction in the total death column entry for β_{CON} = 0.1.

Table 6.4 α-β Tracker Results by Population Class.

Table 6.4. α-β Tracker Results by Population Class.

	Mean Squared Error Equation 6.8 (Standard Deviation)				Performance (Standard Deviation)	
	Rural	$Urban_1$	$Urban_2$	$Urban_3$	Total Deaths (Millions)	Total Nutritional Debt (1000 MT)
$\beta_{NUT} = 1.0$	.831E-5	.925E-5	.861E-5	.170E-4	3.43	47.34
	.221E-5)	(.420E-5)	(.211E-5)	(.332E-5)	(.36)	(11.8)
$\beta_{NUT} = 0.1$	.584E-5	.657E-5	.528E-5	.263E-4	3.47	47.66
	(.190E-5)	(.239E-5)	(.697E-6)	(.555E-5)	(.33)	(25.0)
$\beta_{CONS} = 1.0$	.280E-2	.302E-2	.165E-2	.960E-3	3.43	47.34
	(.174E-3)	(.143E-2)	(.777E-3)	(.131E-3)	(.36)	(11.8)
$\beta_{CONS} = 0.1$	.211E-2	.360E-2	.296E-2	.154E-2	2.73	67.66
	(.143E-3)	(.167E-2)	(.144E-2)	.372E-2	(.27)	(18.0)

was a
6.1-6
for
And
ment
more
rela
havi
prec
mor

tra
par
fec
so
tha
ra
di

ca
p
s

f

One additional test was conducted. The predictor of Equation 6.4 was added to the filter, and each of the simultations covered in Tables 6.1-6.4 was repeated. The predictor produced consistently worse results for every test. All error terms increased, for each variable and class. And total deaths increased significantly each time. The only improvement was provided by a small decrease in total nutritional debt, caused more by the fatality increase than predictor benefits. Evidently, the relatively long periods between sampling points and the oscillatory behavior of the sampled variables combine to thwart the use of a linear predictor. Perhaps a nonlinear polynomial smoothing function would be more appropriate as a predictor.

Test results are inconclusive about the real worth of the tracker. It was decided to include the per-capita consumption filter parameter in later optimization work, because β_{CON} had the greatest effect on system performance. The population class results are similar, so one filter parameter will be used for all four classes. It appears that β_{CON} may be able to influence performance, but results do not warrant additional cluttering of the optimization process. The linear predictor will not be used.

Summary

The information filter is a tool for extracting maximum value from captured data. It is used in conjunction with sample survey design, program and transportation data, and other information inputs to help system managers gain a picture of the problem to be solved.

The α-β tracker tested here is probably not an ideal filter for information system work. One parameter for a per-capita consumption tra

res

ing

per

fil

a (

tracker will be added to the optimization work of Part II. Additional research should be conducted on the Kalman filter and polynomial smoothing to determine their usefulness. It may be that the relatively long periods between samplings negate the positive effects of programmed filters. Human intuition and wisdom are likely to be good filters in a crisis.

by
moc
fo
wh
in
th
pr

fc
tc
a
t
b
m
t
a

CHAPTER VII

MODEL VALIDATION

The worth of any decision making tool depends on its accpetance by the people who would use it. This applies to computer simulation models as well as statistical formulas, charts, graphs, and economic forecasts. A broad definition of validation includes the processes where a tool is shown to reflect real world considitions, to be useful in problem solving, and to be acceptable to users. In general each of these conditions must be met before the model or other tool can help produce practical results.

The purpose of this chapter is a validation of the survival, information component, and cost function models of the preceeding chapters. Certainly, much of the overall validation procedure described above is beyond the scope of this "approach" thesis. Accordingly, the focus here will be on methods for determining whether the model behaves in a sensible fashion. It is hoped that the usefulness of the modeling will be seen along with the validity and usefulness of the entire methodology. The models are not intended to apply in detail to any country. Thus, the desired result here is not to precisely mirror real world magnitudes, but to present a consistent structure with satisfactory outputs, a model suitable for the optimization work of later chapters.

often

volv

eith

figu

data

here

stat

tion

ass

qui

exp

sta

des

va

te

pa

me

CC

co

ar

s

s

p

c

In testing whether a model behaves as it should, validation most often means either correspondence or coherence. Correspondence involves matching model outputs to real world data. This can be done either by tracking past historical data or comparing future real world figures with model projections as time passes. The lack of real world data for hypothetical countries precludes the use of correspondence here. Even in an actual application, the dearth of famine-related statistics will present problems in the use of this particular validation form.

Coherenece, or consistency, refers to observing model outputs and assessing whether they behave in a desired fashion. This method is quite initutive and judgmental; it is imperative that persons highly experienced with the real world system operation be involved at this stage. Many common sense observations are possible. The next section describes several of the tests made on the current survival model.

The importance of reliable data sources becomes apparent in any validation process. The three main data needs in modeling are for system parameters, initial conditions, and technical coefficients. System parameters in the survival model include CGP, the price control parameter from Equation 2.8, and the policy control parameters (CG36, CG32, etc.) in Equations 2.13-2.15. Initial conditions and technical coefficients link the model to the particular country's being studied and to real world natural processes. Necesaary initial conditions in a survival model are population, storage and nutritional levels, and the starting price level. Examples of technical coefficients are the expected harvest yield per acre, YLD, and the nutritional requirement coefficients, UK4 and UK5, found in Equation 2.2.

System parameter levels can be estimated through observation, experiment, or experience. Once the model structure, initial conditions, and technical coefficients are set, system parameter changes are helpful in "tuning" model behavior to parallel real world performance.

Much of the data needed in the current study is not readily available. Where possible, information was gleaned from secondary sources: books, periodicals, private correspondence. The initial conditions and many of the technical coefficients in the survival model followed from Manetsch (38). System parameter feasible levels were derived from estimation and model performance.

The component where the data lack is most acute is the cost function. The coefficients chosen represent educated guesstimates based on the assumed information system form. This is discussed in Chapter V. Because of the unreliable input data, it will be much more significant to analyze relative policy and information quality consequences rather than absolute levels.

An additional word is in order here on the limitations of this model as a realistic simulation of a real world information system. Because the approach is stressed here, the modeling is done on a macro level, so none of the model components is constructed in great detail. Information system alternatives, policy structure, transportation, relief programs, and demographic disaggregations must all be tailored to actual circumstances in the country of application. The lack of complexity is an advantage in that it allows examination of the methodology without many of the details needed in a real case.

Two very important information items that the current model does not cover are health and water data. A lack of water can be more dead

form

dati

VDTD

in t

the

wit

ide

the

ini

moo

ti

ch

ar

or

fo

a

pl

R

o

t

deadly than a food shortage. And disease statistics provide needed information for control of famine-related illness and death.

After the section on general model coherence, three specific validation tests are discussed in this chapter. These involve the SAMPL and VDTDLI subroutines of the sampling component, the effect of changes in the level of crisis, and the simulation cycle DT.

Coherence Tests

The goal of coherence or consistency tests is to determine whether the model behaves in a sensible fashion. One compares model output with expected output and identifies inconsistencies. The comparison identifies the problem area; the next step is to explain or eliminate the problem. Perhaps a coefficient, model structure, parameter, or initial condition change is required. The goal should be a consistent model that is true to the problem being studied.

Five types of consistency checks are possible: variable magnitude; time series interactions; and performance variation with parameter change, policy change, or model structure change. The first two methods are common sense observations involving feasible limits on variable size or expected variable interactions. The performance variations are a form of sensitivity test. The direction of performance change is often a more informative indicator than the magnitude change. Several examples of each consistency check follow.

Testing for sensible variable magnitudes is relatively simple. Real world conditions dictate limitations that computer models must observe. In the early stages of model development it often happens that calculations produce impossible situations, such as negative population or storage totals. Other examples of variable magnitude inconsistencies include the following:

- -- negative or astronomical costs
- -- astronomical market price, PFD
- -- inappropriately timed emergency trigger, EDPC
- -- inordinately large error in population estimates

Price Level

The price level deserves special consideration. In a free market model, price can theoretically expand endlessly, as long as demand greatly exceeds supply. It is likely that the government will take steps to prevent such galloping inflation, to protect the country's economy, and to deal equitably with the food distribution problem. Inflation acts as a screening process for distribution as those with lower incomes are excluded from market participation.

In the current model, the natural place to control price is to fix a ceiling on the rate at which the government sells its grain. In a completely controlled market, the price for private sales would also be fixed and black market operations a common result. If the private sales level is not fixed, a two-tiered rate structure will exist. The government sales ceiling will tend to hold prices down as demand for government grain exceeds demand for private.

The effect of a price ceiling on model behavior is to increase the number of deaths in the urban poor classes. This is in keeping with theoretical economic behavior. A price ceiling increases demand, as reflected in model output. But the lower price also reduces the desire for the rural class to sell; supply is decreased. The critical time period occurs immediately after the harvest start. Without price control, the rurals place enough grain on the market to meet the demands of the rich and sell some to the poor. But the decreased supply caused by decreased price goes only to the rich. Thus, the urban poor suffer; the rurals and urban rich are relatively untouched.

Figure 7.1 indicates the changed rural sales time series due to a price ceiling. Curve A represents the case of market-determined price, while curve B shows the effect of setting a price ceiling at five times the initial price level. The two curves are identical through the preharvest period. Thereafter, the price ceiling curve consistently falls below the free market curve. The peaks in each curve occur as the harvests near their conclusions.

Setting a price limit is an important government decision. It affects food distribution and, ultimately, the distribution of fatalities in the country. Price level will be an important piece of information for decision makers to observe; it is a possible early warning signal of food shortages.

The current model assumes no government price setting. The reasoning behind this assumption is that any chosen ceiling would be purely arbitrary. Different countries and different circumstances will cause varying criteria to be used for price setting. The result of not controlling price explicitly in the model is very high prices. At the crisis peak, the grain price is more than fifteen times the initial level. This runaway inflation produced by the model was initially a cause for concern. Consistency demanded an explanation, which has been provided in the previous paragraphs.

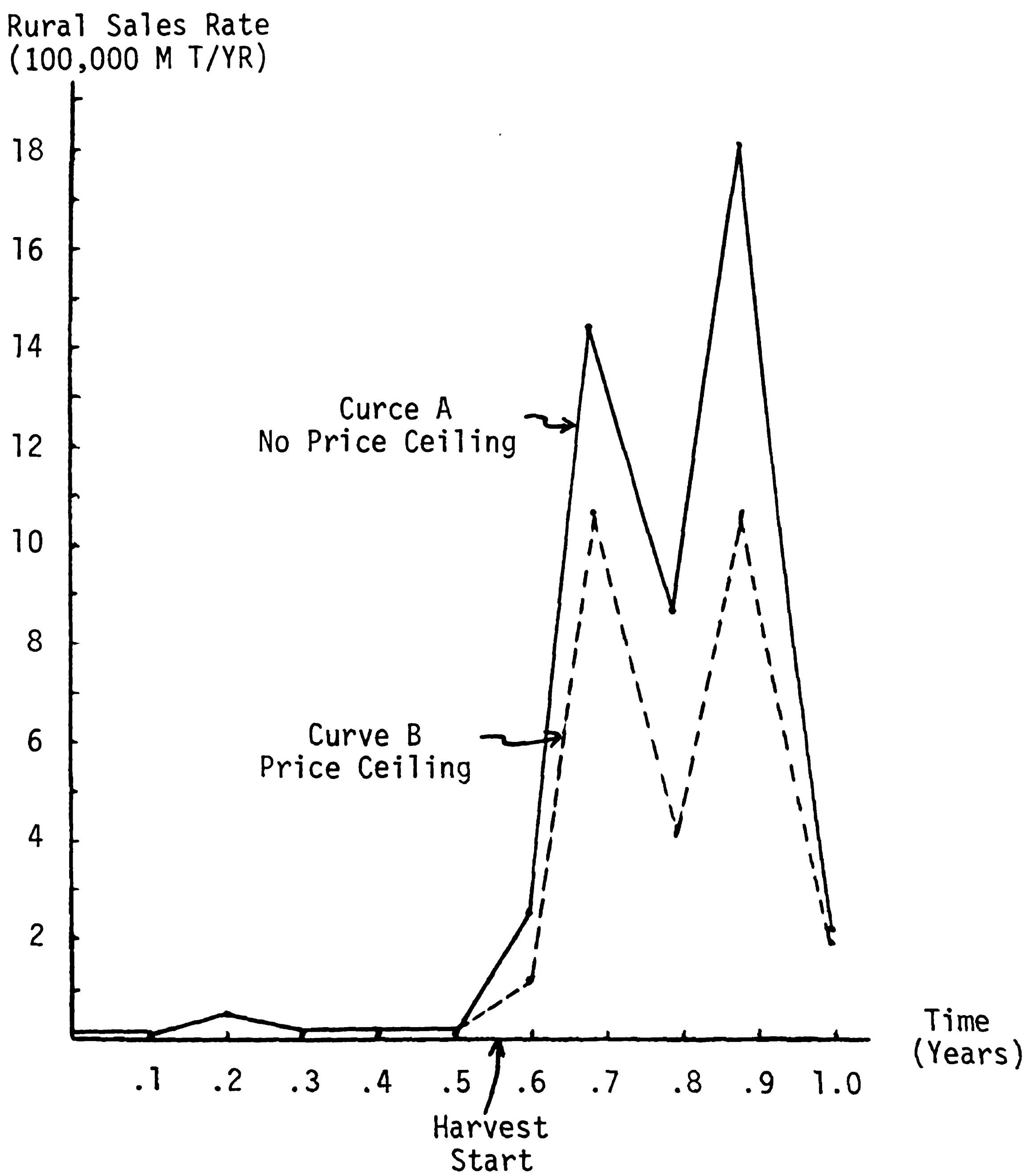


Figure 7.1. Effect of Price Ceiling on Rural Sales Rate

One result of high prices is attractive, the possibility of generating revenue by selling government grain only to the very rich. The receipts could then be used to finance emergency aid and acquisitions programs.

Conservation of Flow

The second type of coherency test is an examination of two or more variable time series that are intuitively related. In general, conservation of flow must be preserved. For example, the harvest rate should be reflected in storage levels. As the harvest proceeds, rural private storage should increase. The end of the harvest should signal an end to storage increases; consumption should cause storage to decline. By examining model outputs one can observe the behavior and compare it to the assumed desirable performance. The dynamic nature of the simulation allows convenient generation of appropriate time series.

If model behavior is not as expected, an explanation must be found. For the harvest and storage example, weather factors may have been set to significantly reduce crop yield, causing consumption to outstrip production. Government acquisitions may be extremely heavy, depleting private stores. Either case would cause an apparent model inconsistency.

Other time series checks conducted on the current model include the following, each of which the model handled well.

- -- increased private storage effect on consumption
- -- increased total storage effect on average available nutrition rate, ARNUT
- -- decreased price level effect on private sales
- -- relationship between nutritional level and death rate
- -- relationship between storage and transportation

-- effects of government sales, acquisitions, and emergency aid on consumption

Sensitivity Tests

The change in system performance as parameters are varied is an important sensitivity test. The direction of system performance change is a good indicator of model consistency. An excellent example of this type of test was presented in Chapter IV. It was assumed that better information quality, represented by decreased values of the vector $\underline{X}$, should produce fewer deaths or a lower total nutritional debt. Much of Chapter IV is devoted to policy structure and modeling changes initiated because the information quality assumption was violated. These changes are summarized shortly.

A system parameter sensitivity test is easy to conduct. The simulation is conducted twice, each time with a distinct value for the parameter under study. A defined system output is measured at the end of each run. The output change should follow an assumed pattern. For example, decreasing the sampling interval or the delay time (information quality parameters) should cause total deaths to decrease.

Three system performance outputs were used in parameter sensitivity tests. Two are the members of the $\underline{F}$ performance vector of Equation 4.2: total deaths and total nutritional debt. The third output is the percentage of famine-related deaths by class, as computed in Equation 7.1. These PERCD figures provide a measure of policy and parameter effects on the different demographic groups.

$$PERCD_j(t) = TDETHC_j(t) \ / \ POP_j(0) \quad (7.1)$$

where:

PERCD = class percentage deaths

TDETHC = class deaths (persons)

POP(0) = initial population (persons)

j = index on population classes.

Certain parameter sensitivity tests are discussed in some detail in Chapter VIII. The goal there is to identify policy parameters whose effect on system performance is sensitive to changes in information quality or crisis level. Many sensitivity tests were conducted on policy and information quality parameters. A major result of these tests is a policy parameter vector $\underline{P}^0$ that is very nearly "optimal." Optimality is defined with total deaths as a primary criterion and minimum total nutritional debt secondary. $\underline{P}^0$ was found with a fixed perfect information vector $\underline{X}$.

The following parameter tests were also satisfactorily concluded:

-- the effect of relatives' emergency aid parameters RK1 and RK2 on fatality percentages

-- the effect of information quality changes on costs

-- the effect of population estimation on system performance

Policy and model structure modifications will generally have a large impact on system performance. The modification should be made with a specific purpose in mind. Chapter IV describes several such changes. In many ways that chapter serves as a model consistency discussion. The modifications addressed there include the following:

-- policy changes for more efficient relief operation

  -- early acquisitions to force rural population to conserve

  -- deletion of urban private storage as a useful decision variable

-- provision of possible increased transport rates to meet distribution problem

-- limited acquisitions immediately preceeding harvest to avoid impractical and inefficient activity

-- model changes to more accurately represent real world

-- rural consumption pattern

-- hand-to-mouth urban consumption at crisis peak

-- rural sales pattern

-- government desired storage levels

-- minimal sales provision

The full range of issues and decisions facing decision makers cannot be addressed in the relatively crude model used here. Based on numerous tests and checks, it appears that the model does consistently cover the effect of an information system on famine relief operation.

Sampling Component Validation

The sampling component described in Chapter III is intended to model the complex data collection, processing, and transmission processes of an information system. Information quality parameters for measurement error, sampling frequency, and lag time are used to represent (and avoid) the details of the actual system. The input to the sampling component is a series of "true" values generated by survival model simulation. Output is a time series representing the lagged, sampled, and stochastic estimates that system managers would receive. Varying the quality parameters allows generation of a wide range of estimates.

In this section, the ability of the sampling component to track a given input series is examined. The test signal is the function $h(t) = 2\sin(2t)$, whose oscillatory behavior will allow the estimation properties of the routine to be seen. Function h(t) is fed to the FORTRAN subroutines SAMPL and VDTDLI and outputs are observed. The discrete simulation interval DT is set at .05 and the run duration is 4.0 units to allow completion of one sinusoidal cycle.

Two distinct information quality vectors are used in the subroutines, one consistently "better" than the other. The vectors are presented in Table 7.1, with values for sampling inteval (SAMPT), time lag (DEL), and measurement standard error (SD).

Table 7.1. Information Quality Vectors Used in Sampling Component Tracking Test.

	Good Vector	Poor Vector
SAMPT	.2	.3
DEL	.1	.3
SD	.2	.4

Figure 7.2 pictures the resulting true function and sampling component estimates. The smooth curve A is the true function while curves B and C represent the good and poor information quality vectors, respectively. There are four indicators in Figure 7.2 that the sampling component is behaving as desired. The fact that output values for a given curve are in small horizontally equal groups represents the sample-and-hold estimation property. The output is actually a step function. The different group length between curves B and C indicates the changed sampling interval; the group length and sampling interval for curve C are one and one-half times those of curve B.

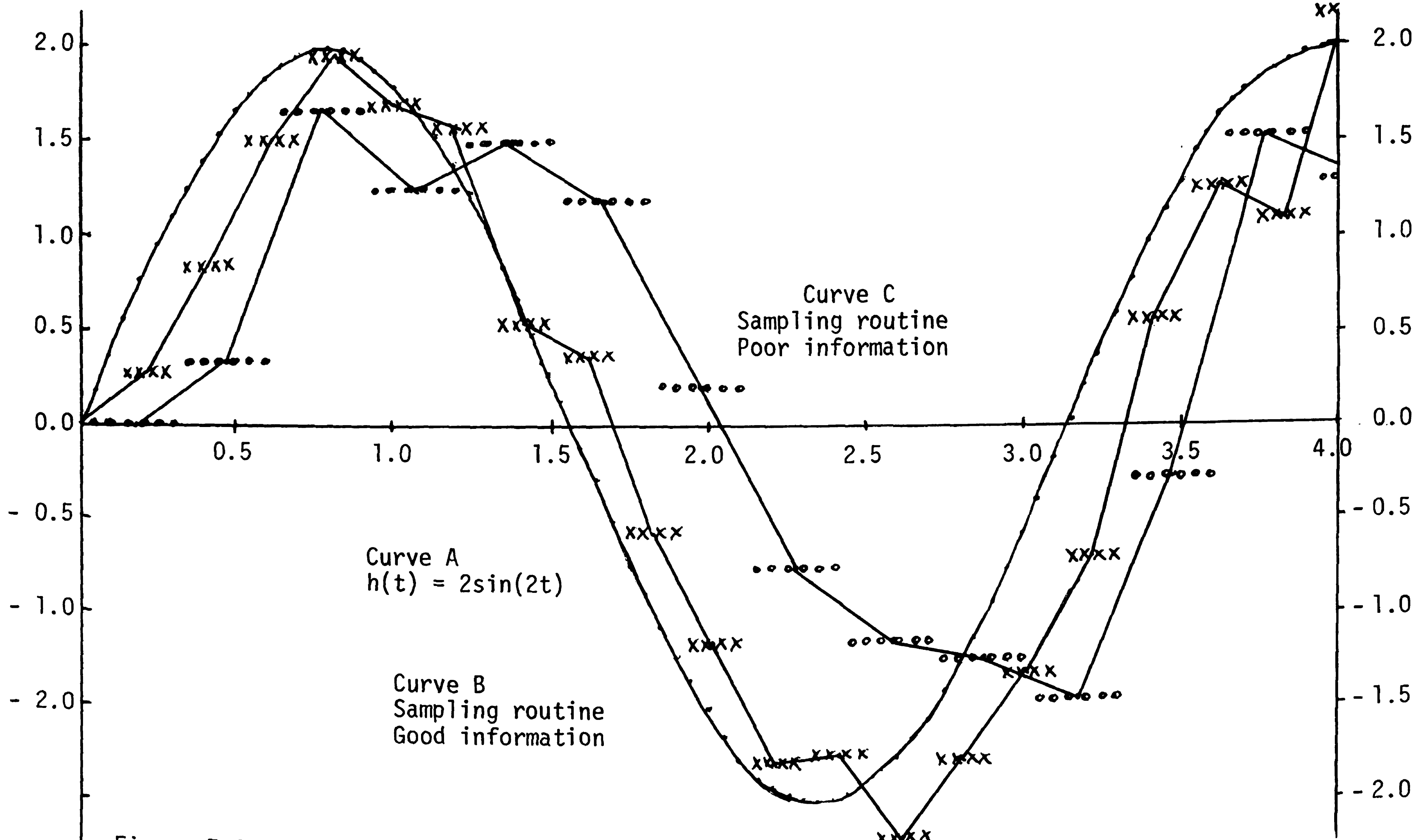


Figure 7.2. Sampling Component Tracking Test

Curves B and C are drawn through the midpoints of the output steps to provide a feeling for the shape of the estimated curve. Note that curve C is generally to the right of curve B, reflecting the difference in delay parameters. And curve C is a more distorted version of the true function than is B, tending to flatten out the true oscillations. This is caused by the larger measurement error at each step.

This graphical test has shown that the sampling component represented by routines SAMPL and VDTDLI behaves as desired.

Crisis Level Variation

The crisis level and the extent of outside aid are probably the two most important exogenous factors impinging on a famine relief system. The outside aid problem has been examined elsewhere (38). The current model assumes that no international aid is available. The crisis level can be measured as the expected shortfall of food. Crisis level affects the size and often the structure of the relief system. It will also determine the magnitude of many information quality policy parameters, the rates at which relief operations take place. Thus, the expected crisis level must be accounted for in later optimization work.

The survival model provides a simple means of determining crisis level. Events before the start of simulation are ignored; the initial conditions describe the setting. In particular, the initial value of rural private storage (RSTOR(0)) corresponds to crisis level. It is assumed that an emergency has not been declared before the simulation start. The market, the government, and the citizens are operating normally until that time. The rural class is the largest single holder of grain stocks, and it is this storage amount that is critical. Initial government storage levels are also very important, but are left constant in this study.

All of the previous model results and testing have been done with an initial RSTOR equal to 2.0 million metric tons of grain, a medium level crisis for the hypothetical country.

The purpose of this section is to show that initial rural private storage can be used as a proxy for crisis level. This is done by conducting survival model simulations with several different initial RSTOR values and observing the results.

Figure 7.3 contains graphs of total deaths (TDETH) as functions of initial RSTOR level. Information quality is assumed to be perfect. The price control curve A indicates expected fatality totals with little government intervention beyond normal price control policies. The curve B shows the results of active government acquisitions, sales, and emergency aid programs. The graphs indicate that deaths increase dramatically as the level of available food decreases. Note also that the equalization programs consistently perform better than the price control policy.

A second validation test is available for the use of initial RSTOR as crisis level proxy. It was mentioned earlier that crisis level will have a substantial impact on policy parameters. The equalization policies are designed to minimize deaths and nutritional debt by spreading food equally across the demographic classes. Each of the simulation runs made to produce curve B of Figure 7.3 employed a policy parameter set $\underline{P}_{2.0}$ that has been found to be very good for runs with RSTOR(0) at the 2.0 million level. Percentage deaths by class ($PERCD_j$) indicate

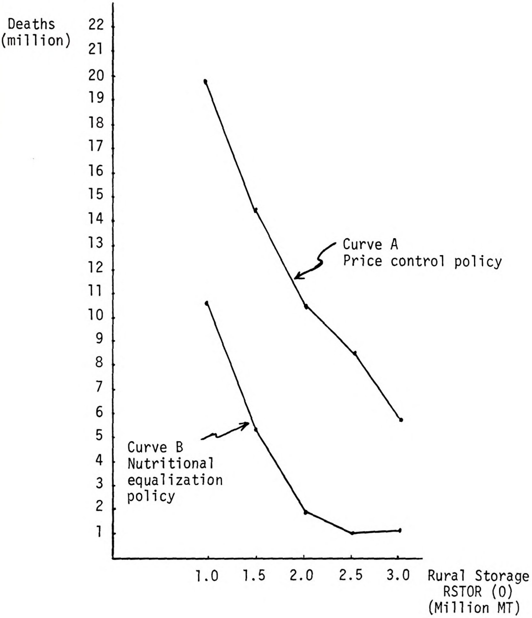


Figure 7.3. Total Deaths as a Function of Initial Rural Private Storage

that changing the initial RSTOR value greatly affects the ability of $\underline{P}_{2.0}$ to fairly distribute grain.

Figure 7.4 charts percentage deaths versus initial RSTOR for three of the four population groups. Note that the percentages are closest to equality at the initial storage level where $\underline{P}_{2.0}$ was derived. Increased RSTOR(0) causes deaths to fall dramatically, with the urban poor classes suffering slightly higher fatalities. The rural class is most affected when RSTOR(0) falls. The rich class is always relatively well off.

The curves in Figure 7.4 reveal two interesting facts about the model. First, RSTOR(0) influences the "optimal" magnitude of policy parameters. A needed assumption here is that policy parameters can affect the equalization of percentage deaths by class. The second observation is that class differences are as expected over a wide range of initial conditions. The rich are least affected by the food crisis. The rural group and poor urbans are most dependent on the size of government policy parameters. It appears that the large death total in the rural class for RSTOR(0) = 1.0 million is a result of acquisition rates intended for use at the 2.0 million level of RSTOR(0). The parameters used are too stiff for the case of decreased food availability.

Varying RSTOR(0) affects total deaths and the class fatality distribution in a manner expected of a crisis level. Thus, initial rural private storage is used in later work as a proxy for crisis level.

Simulation Interval DT

The last item to be discussed in this chapter is the mathematical approximation process of a discrete, dynamic simulation. Each of the equations used in the model is only an approximation of a real world

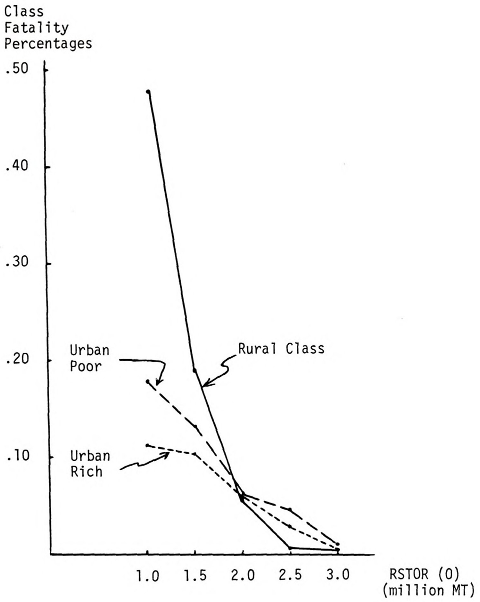


Figure 7.4. Class Fatality Percentages as Functions of Initial Rural Private Storage

ocess. Further error is introduced when numerical solutions to the
eoretical equations, most of which involve continuous non-linear
unctions, are calculated in a discrete computer model.

A common computation in the model is numerical integration using
he Euler technique. The theoretical integration form given in Equation
.2 has been used many times in earlier chapters. The Euler numerical
olution for Equation 7.2 consists of the approximation in Equation 7.3
which calculates successive values as the simulation advances through
time.

$$\text{LEVEL}(t) = \int_0^t \text{RATE}(s)\, ds \tag{7.2}$$

$$\text{LEVEL}(T+DT) = \text{LEVEL}(T) + DT * \text{RATE}(T) \tag{7.3}$$

where:

LEVEL = variable resulting from integration

RATE = integrand variable

0,t = limits of integration

s = dummy integrand variable

T = time in computer simulation

DT = discrete time interval.

Theoretically, the integration in Equation 7.2 is the limiting calculation of Equation 7.3 as DT approaches zero. This would imply that the numerical approximation error in simulating integrations should decrease with DT. The distributed delay described in Equation 2.18 is another numerical calculation whose error decreases with DT. So all else being equal, model outputs should approach limiting values as the model is run with smaller and smaller DT. This is, in fact, the case h the current model, as outputs approach limits for DT near .00025 ears).

For numerical accuracy, a small DT value is desired. But smaller intervals also cause increased computer time and increased costs. a tradeoff must be made. Generally, the solution is to choose the rgest DT that provides acceptable accuracy. The cost consideration quite important in the current methodology since many model runs ill be required later for sensitivity tests and optimization work.

The numerical results of simulations with DT equal .00025 and 002 are compared in Figures 7.5 and 7.6. Total death (TDETH) calcula-ions are graphed in Figure 7.5 and total nutritional debt (TNUTD) is raphed in Figure 7.6. These two variables reflect the numerical fluc-uations of most other model variables and are the variables by which ystem performance will be judged.

The curve shapes are essentially the same for both DT values. Note that the error in Figure 7.5 using DT = .002 increases as time advances. This is typical of numerical integration results, since earlier errors are compounded. The curves for total nutritional debt are quite close throughout the simulation.

An increase of DT to .004 causes some unacceptable numerical problems, particularly with the relationship between nutritional level and death rate. Thus, DT equal to .002 has been used for all simulation work.

Summary

The validation process described in this chapter is a set of tests to determine whether the current computer model behaves sensibly. The

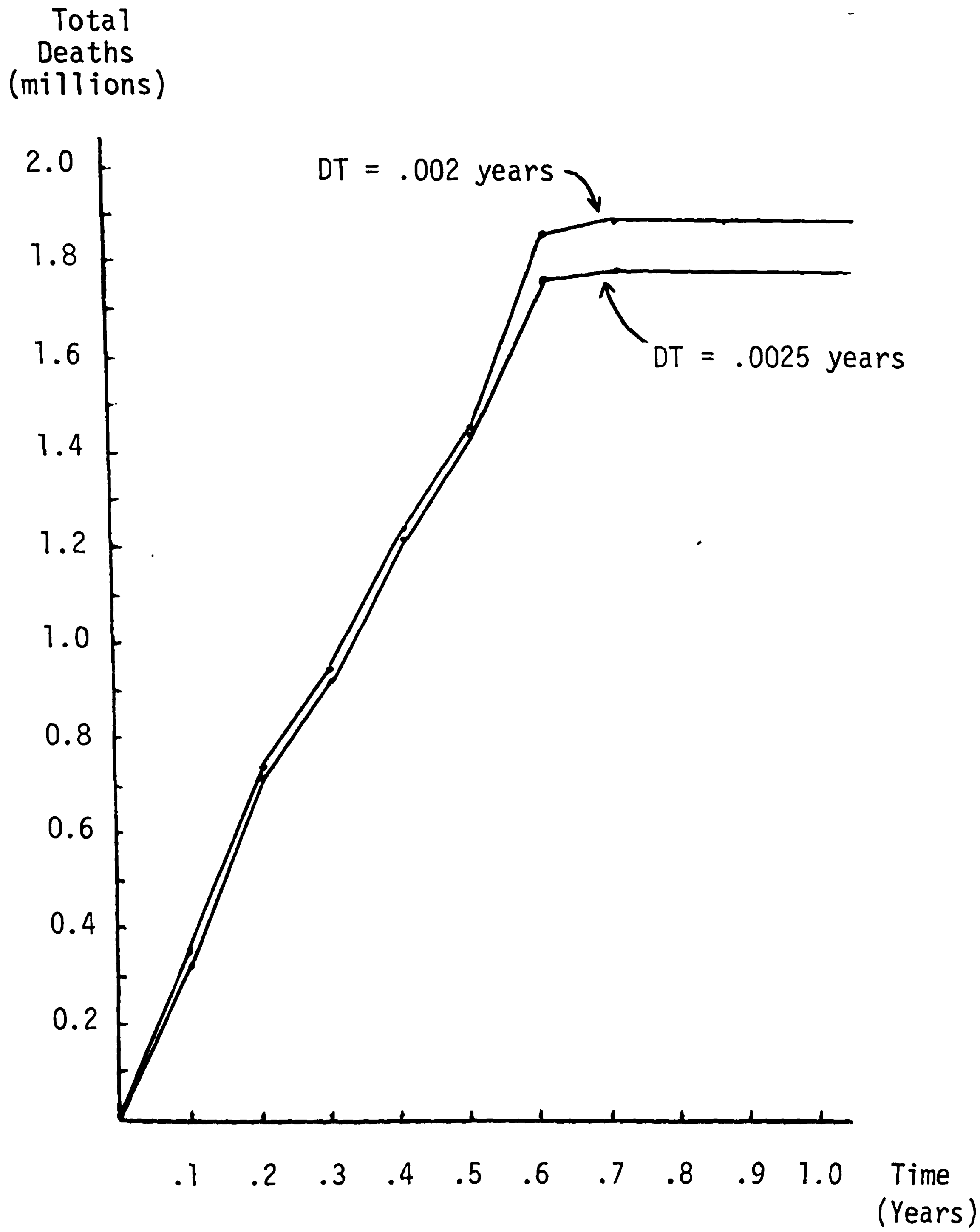


Figure 7.5. Total Deaths Simulated with Varying DT Values

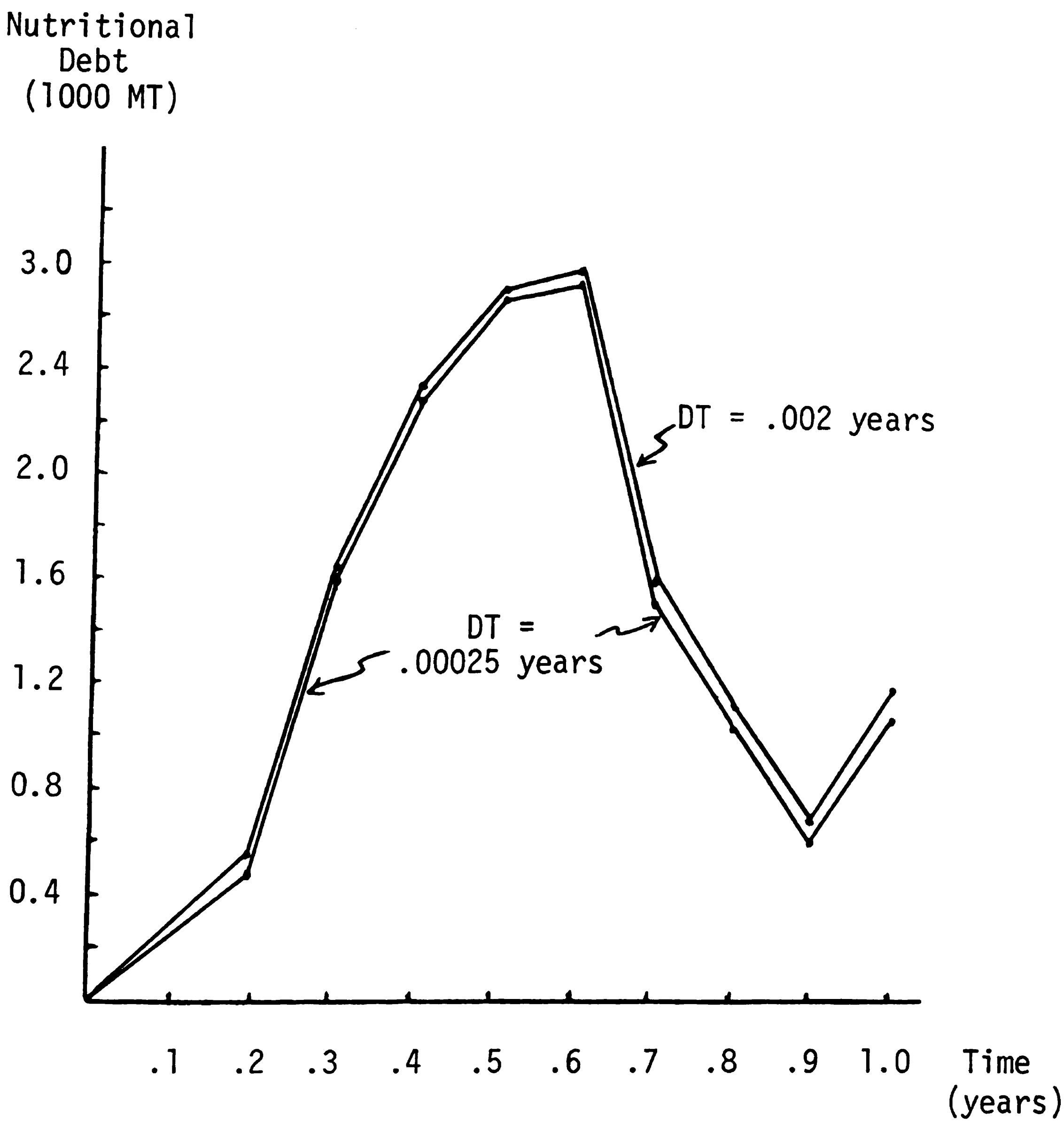


Figure 7.6. Total Nutritional Debt Simulated With Varying DT Values

lack of hard data means that a statistical fit with real world experiences is not possible. Thus, the judgments made here are based on intuition and background knwoledge of the problem. The model is now ready for the optimization work of Part II.

PART II

OPTIMIZATION APPLICATION

CHAPTER VIII

OPTIMIZATION PRELIMINARIES

One of the biggest problems in simulation and optimization work is having to deal with numerous independent, interacting variables. The number of variables is an important consideration; normally, the experimental load increases at least as the square of the number of variables. The size of the observation space is also crucial. The tighter the limits placed on parameters under study, the more likely it is that one finds an accurate response surface. Not only does optimization become more difficult as the parameter space increases, but computer costs increase and reliability often decreases.

The advantage of including many parameters in optimization work comes from the use of the most general model available. The mistake of ignoring important variable interactions is more likely when parameter size is limited. But it is not always possible or wise to use every decision parameter and variable in the optimization phase. A very good question to be answered is which variables should be included to capture the most crucial aspects of the decision process. In other words, which parameters have the most effect on system performance? The tradeoff is obvious. By sacrificing some of the accuracy present in the most general model simulations, a more manageable problem is obtained. Difficulty, time, and cost savings are traded for generality and accuracy.

The mathematical formulation for the optimization problem is repeated here as Equation 8.1. In this case minimization of the observation space would imply two things. First, the dimension of the combined vector $(\underline{X},\underline{P})$ should be as small as possible. And second, the ranges between vectors $\underline{E}_1$ and $\underline{E}_2$ and between $\underline{D}_1$ and $\underline{D}_2$ should also be minimal.

$$\text{Minimize } \underline{F}(\underline{X},\underline{P}) \quad (8.1)$$

$$\text{subject to } G(\underline{X}) \leq C$$

$$\underline{D}_1 \leq \underline{X} \leq \underline{D}_2$$

$$\underline{E}_1 \leq \underline{P} \leq \underline{E}_2$$

where:

$\underline{F}$ = system performance vector (F_1=total deaths, TDETH; F_2=total nutritional debt, TNUTD)

G = cost function (monetary units)

$\underline{X}$ = information quality vector (sampling frequency, measurement error, time lag)

$\underline{P}$ = policy parameter vector (rates and triggers)

$\underline{D}_1,\underline{D}_2,\underline{E}_1,\underline{E}_2$ = parameter constraints

C = budgetary constraint.

One of the objectives of this chapter is to discuss means of minimizing the observation space needed in the next chapter. The information quality vector $\underline{X}$ has been limited and well-defined in Chapters V and VI. It is given in Table 8.3. Thus, the policy parameter set $\underline{P}$ will be the focus here. In exploring methods for identifying sensitive

X and P parameters, it is hoped that some understanding will follow of the relative overall importance of policies, information quality, and crisis level. These preliminaries should shed some light on difficulties and expediencies to be encountered later.

The next section gives a more detailed introduction to the parameter limitation problem. Following that are sections discussing a straightforward "sensitivity test" solution and a computer search algorithm. The last section presents a summary and conclusions. From hindsight it is clear that an algorithm is the quickest way to obtain useful results. The sensitivity test section is included mainly to illustrate the complexities that abound when a nice algorithm is unavailable and to indicate possible alternative analysis tools in such a case.

Sensitivity Test Design

Let us now turn to the matter of selecting the most "sensitive" policy parameters. Recall the overall goal of this dissertation: design of an information system for famine relief. Thus, the problem formulation of Equation 8.1 implicitly assumes that the P vector will contain only parameters related to the information system.

The objective function F is sensitive to changes in the policy parameters. This was demonstrated in Chapter IV. It is also true that some policy parameters are "sensitive" to changes in information quality. That is, when working with values of X and P that produce "optimal" F results, a change in the X vector often leads to a corresponding change in the P vector to restore an "optimal" condition at the new X vector. A concrete example is useful. Suppose that Equation 8.1 has been solved with vectors $\underline{X}^0$ and $\underline{P}^0$. Then, suppose that information

system resources are reduced, causing a general decrease in information quality. Simulation results show that the emergency transportation rate should be increased to partially offset the use of poorer data. Evidently maintaining urban stores at a certain level is very desirable, but faulty reports on the nutritional standing of the urban population can allow storage to fall dangerously. Increased transport volumes serve as an insurance against low grain levels. We are searching for such P variables, those that change optimal value with information quality X.

Policy Parameters

Table 8.1 contains a set of fifteen policy parameters from Chapters II, III, and IV. A description, the units of measure, and the specific equation numbers are given to help identify the parameters which were chosen from the policy rules and transport and storage equations.

Several of the Table 8.1 variables can be eliminated immediately. Urban private storage was shown in Chapter IV to be an unnecessary data item. Therefore, the control parameter CG34 is deleted. The normal transport rate CG1 can be ignored since a crisis transport parameter CG25 has been included in Table 8.1. Note that CG25 and CG1 both appear in Equation 4.5; examination of that equation shows that the former "covers for" the latter.

The use of CG25 also partially explains the deletion of the desired government storage levels GSUD and GSRD. The transport parameter serves as a proxy in the decision rule of Equation 4.5.

Table 8.1 Original Policy Parameter List

NAME	DESCRIPTION	UNITS	EQUATION
CG1	Normal transport rate, urban-to-rural	$year^{-1}$	2.10, 4.5
CG21	Emergency trigger for declaration of famine	MT/person	see 2.11
CG24	Consumption control, emergency food equation	$year^{-1}$	form in 3.8
CG25	Crisis transport increase parameter	none	4.5
CG27	Nutritional debt control, emergency food equation	$year^{-1}$	2.15
CG30	Rural private storage control, acquisitions equation	$year^{-1}$	2.13, 3.8
CG32	Nutritional debt control, sales equation	$year^{-1}$	2.14
CG34	Urban private storage control, emergency food equation	$year^{-1}$	2.15
CG35	Consumption control, acquisition equation	$year^{-1}$	3.8
CG36	Nutritional debt control, acquisition equation	$year^{-1}$	2.13, 3.8
CG45	Rural private storage control, early acquisitions	$year^{-1}$	4.3
CG81	Average nutritional availability control	none	4.13
GDE	Consumption control, sales equation	$year^{-1}$	form in 3.8
GSRD	Desired government rural storage	MT	2.10, 4.5, 4.6, 5.8
GSUD	Desired government urban storage	MT	4.5, 5.8

A simplified explanation of Equation 4.5 is that no emergency transport is allowed if GSUD is too low or if GSRD is too high. Simulation results tend to concur that maximizing GSUD and minimizing GSRD are good choices. Actually, system performance is not appreciably affected by wide variation in the value of either storage level setting.

The initial rural storage level chosen to represent a medium crisis obviates the use of the emergency trigger CG21. The famine is severe enough that some positive level of nutritional debt is to be expected throughout the one year simulation cycle. The only deviation occurs when several million people die quickly, allowing the remaining food to be spread among fewer survivors. But this is clearly non-optimal according to the primary objective of minimizing deaths. It should be noted that CG21 is deleted here because of the crisis setting for <u>this</u> experiment. Normally, a good value of CG21 will be of primary interest to planners.

The final parameter to be deleted is perhaps the most interesting. CG81 was intended as a control on the target nutritional debt level. It was felt that a final control on that complicated calculation may help to compensate for measurement errors. But all preliminary testing under varying conditions demonstrated that deviation of CG81 from a unit value in either direction could only worsen the results of the famine. It may be that such a control is useful only if it can vary with time or under different crisis conditions. CG81 is excluded from consideration here because it showed little inclination toward varying from one under any information quality setting. Further examination of this area is recommended but is not pursued here.

Several reasons have been given for parameter elimination. CG34 should actually have never made the initial list, because it no longer is part of the policy structure. Any contribution from CG1 or the storage level parameters could be covered by the included variable CG25. The storage levels as well as CG81 are eliminated because they had little effect on performance. CG21 (and the storage levels) are excluded because the simulated famine milieu renders them inconsequential. An understanding of the model and familiarity with simulation results lead to confident conclusions about the worth (or non-worth) of several variables without rigorous testing.

Model testing and simulation results were mentioned as one of the criteria for eliminating six of the original fifteen policy parameters. This testing also serves as a powerful tool for determining reasonable limits on the size or range of the remaining parameters. Note also that assigned units help in setting limits. In general a rate unit (such as $year^{-1}$) cannot be negative. A rate's inverse represents the amount of time expected to pass until the estimated and target control values are equal, if all else remains the same.

For example, nutritional debt controls CG27, CG32, and CG36 all have rate units ($year^{-1}$). This can be interpreted to mean that for a control setting of C, the gap between measured nutritional debt should be closed in 1/C years. Thus, a value of any of these parameters greater than twenty-five would lose its practical value, because nutritional debt changes take longer than one twenty-fifth year (two weeks) to accomplish.

Logic dictates an initial range of acceptable parameter values. Numerous simulation runs at varying parameter levels help to further

limit known useful ranges. It should be noted that the equations in Chapters II and III, particularly 2.13-2.15, were constructed to produce control parameters with some practical interpretation. This is an excellent modeling practice.

By following the above logical and experimental approach, limits were derived for each of the remaining nine policy parameters. These values will be used in the next three sections and are given in Table 8.2. Descriptions and units are repeated from Table 8.1.

Test Methods

The methods to be used to determine the sensitivity of the nine policy parameters are similar to those outlined in the first section of Chapter IV. Three information quality vectors are chosen, representing clairvoyant, good, and poor data values. At each fixed $\underline{X}_k$, a study is done on the policy parameters $\underline{P}$. Study results are compared across the $\underline{X}_k$'s to determine which $\underline{P}$ variables change with $\underline{X}$. Those that vary will be included in Chapter IX research. Others will be assigned a value close to their demonstrated "best" values. The $\underline{X}_k$ are displayed in Table 8.3. Again, descriptions, units, and equation numbers are provided.

Several factors must be included in the test design to allow a fair observation of each policy parameter's worth. First, the famine crisis level must be accounted for. Recall the discussion in Chapter VII concerning the use of the initial rural private storage level (RSTOR(t=0)) as a proxy for crisis level. Second, the $\underline{X}$ vectors as defined in Table 8.3 will introduce a stochastic nature to model results. Statistical, Monte Carlo methods will be needed to assess the

NAME	DESCRIPTION	UNITS	LOWER LIMIT	UPPER LIMIT
CG24	Consumption control, emergency food equation	$year^{-1}$	0.0	15.0
CG25	Crisis transport increase parameter	none	1.0	5.0
CG27	Nutritional debt control, emergency food equation	$year^{-1}$	0.0	25.0
CG30	Rural private storage control, acquisitions eg.	$year^{-1}$	0.0	25.0
CG32	Nutritional debt control sales equation	$year^{-1}$	0.0	12.0
CG35	Consumption control, acquisitions equation	$year^{-1}$	0.0	0.1
CG36	Nutritional debt control, acquisitions equation	$year^{-1}$	0.0	8.0
CG45	Rural private storage, early acquisitions control	$year^{-1}$	0.0	1.0
GDE	Consumption control, sales equation	$year^{-1}$	0.0	0.1

Table 8.2

Policy Parameters to Be Used in Sensitivity Testing

Table 8.3 Information Quality Parameter Settings $\underline{X}_j$

PARAMETER	DECRIPTION	UNITS	EQUATIONS	CLAIRVOYANT X_1	GOOD X_2	POOR X_3
SDND	Standard error, nutritional debt measurement	None	5.18, 5.25, 5.26, 5.36	0.0	.0005	.001
SDRC	Standard error, consumption measurement	None	5.29, 5.31, 5.36	0.0	.05	.1
SDRS	Standard error, rural private storage	None	5.30, 5.32, 5.36	0.0	.05	.1
SAMPT	Sampling interval, nutritional debt surveillance	Years*/Survey	5.18, 5.25, 5.26, 5.36	.002	.02	.06
SMPRC	Sampling interval, consumption surveillance	Years*/Survey	5.29, 5.35	.002	.02	.06
SMPRS	Sampling interval, storage surveillance	Years*/Survey	5.30, 5.36	.002	.02	.06
DELD	Information reporting delay	Years	5.18, 5.35, 5.36	.004	.01	.03
CG29	Consumption α-β tracker parameter β_{CON}	None	6.1-6.3, 6.6	1.0†	1.0†	1.0†

*Note .02 years ≈ 1 week
†Sample-and-hold case

significance and credibility of test results. The third factor to be considered is the multiple response nature of the objective function $\underline{F}$.

Two distinct test procedures will be described in this chapter. The first is a standard sensitivity test, where each policy parameter P_j is allowed to vary separately, and changes in $\underline{F}$ are observed. The second involves an optimization algorithm will all parameters varying at once. The handling of crisis level and multiple responses is different for each test and will be explained in the respective sections. Randomness has the same implementation in both tests and will be described here.

The stochastic nature of the model is introduced when $\underline{X}$ parameters SDND, SDRC, or SDRS are non-zero (see Table 8.3). Equations 3.10 provide an algorithm for sequential computation of the average and standard deviation for a string of samples.

An important variable to monitor when conducting Monte Carlo simulation experiments is the number of individual model runs used to compute statistics. MONRUN will be used for this purpose in the rest of the dissertation. Acceptable values for MONRUN are needed to allow significant results for good and poor $\underline{X}$ vectors. Note that with a clairvoyant $\underline{X}$, no randomness is introduced and MONRUN equal one will suffice. (A good check on the model implementation of Equations 3.9 is to set MONRUN greater than one in a non-random situation. The standard deviations should always be zero).

A short test was conducted to determine likely MONRUN levels. Since Equations 3.9 provide statistics after each model run, MONRUN was set to ten and results were monitored for each run. The test was performed for both good and poor $\underline{X}$. Statistical results are given in

Table 8.4. Total deaths (TDETH) and total nutritional debt (TNUTD) are computed and averaged over the ten model runs. In this test, the change in standard deviation over the course of the runs is an important statistic. Also note the percent standard deviation column. Note that for TDETH, the standard deviation stays in a fairly narrow band for both the "good" and "poor" information cases. The deviation decreases with MONRUN in the "good" case, but oscillates in the "poor" case. This would indicate the use of a higher MONRUN for poor X than good X, which would be a logical assumption. It appears that a fairly small MONRUN value can be used without undue statistical error. Due primarily to research budget considerations, MONRUN equal to two, three or four will be used in the remaining chapters.

Nutritional debt statistics are much less promising. The average figure and the standard deviation both take large jumps on several occasions, revealing model runs where nutritional debt calculations vary considerably from any norm. Note especially the sixth and ninth runs for "good" X and the fourth run for "poor" X. This indicates that TNUTD is not as good an objective value as TDETH, because of its statistical limitations.

Standard Sensitivity Tests

Standard one-variable-at-a-time sensitivity testing involves the study of the effect on system performance caused by a change in the one variable. Comparison of performance effects across several variables allows one to determine the sensitive parameters, those that cause the largest change in performance,

Table 8.4 Averages and Standard Deviations of Objective Values for Good and Poor Information Quality Stochastic Testing

	"GOOD" $\underline{X}_2$ VECTOR		"POOR" $\underline{X}_3$ VECTOR	
Monrun	Total Deaths (Millions) (S.D.) (% S.D.)	Total Nutritional Debt (1000 MT) (S.D.) (% S.D.)	Total Deaths (Millions) (S.D.) (% S.D.)	Total Nutritional Debt (1000 MT) (S.D.) (% S.D.)
1	3.065 (0.0)	38.83 (0.0)	3.720 (0.0)	25.96 (0.0)
2	3.175 (.155) (.05)	37.27 (2.21) (.06)	4.026 (.433) (.11)	26.52 (0.79) (.03)
3	3.246 (.165) (.05)	35.91 (2.83) (.08)	4.075 (.318) (.08)	24.78 (3.06) (.12)
4	3.235 (.136) (.04)	36.44 (2.54) (.07)	3.922 (.401) (.10)	29.94 (10.6) (.35)
5	3.179 (.172) (.05)	37.26 (2.87) (.08)	3.983 (.373) (.09)	32.63 (10.9) (.33)
6	3.204 (.165) (.05)	38.61 (4.17) (.11)	3.963 (.337) (.09)	32.12 (9.90) (.31)
7	3.210 (.152) (.05)	38.09 (4.05) (.11)	3.976 (.309) (.08)	29.95 (10.7) (.36)
8	3.218 (.142) (.04)	37.71 (3.90) (.10)	3.958 (.290) (.290)	29.70 (9.94) (.33)
9	3.221 (.133) (.04)	40.25 (8.45) (.21)	4.092 (.484) (.12)	27.15 (12.0) (.44)
10	3.227 (.127) (.04)	41.32 (8.66) (.21)	4.077 (.458) (.11)	26.25 (11.7) (.45)

The most valid use of standard sensitivity testing would start with definitions of an appropriate objective function based on $\underline{F}$. Then for the information quality vectors $\underline{X}_1$, $\underline{X}_2$, and $\underline{X}_3$, best policy vectors $\underline{P}_1^0$, $\underline{P}_2^0$, and $\underline{P}_3^0$ would be determined. Differences in the optimal policy vectors would indicate sensitive policy parameters. Unfortunately, finding $\underline{P}_j^0$ is a very difficult task when using one-at-a-time sensitivity tests. An alternate approach is suggested. Since the goal is not to find optimal $\underline{P}$'s but, rather, to find sensitive $\underline{P}$ parameters, the direction of change in system performance will be used as a sensitivity indicator. A note of caution is issued; the following formulation does not always lead to well-defined results.

The procedure followed here was a multi-stage analysis using a complicated but limited series of model runs and avoiding the use of an optimization algorithm. Previous testing of the model had produced a set of parameters $\underline{P}$ that provided a good system performance when combined with the clairvoyant vector $\underline{X}_1$. Using this set as a starting point and keeping $\underline{X}_1$ fixed, a manual gradient search technique was employed to identify a "best" policy vector $\underline{P}_1^0$. (The definition of "best" will be discussed shortly.) The search involved varying each parameter a short distance from its base value and examining the performance results. When performance improved, the better parameter value was substituted to create a new base vector. In this manner the base vector produced better and better results and hopefully approached $\underline{P}_1^0$.

Once a satisfactory $\underline{P}_1^0$ was determined, a second set of tests were conducted at the different information quality levels and at varying crisis levels. $F(X_1, P_1^0)$ serves as a base performance for the clairvoyant $\underline{X}_1$ and crisis level RSTOR(0). Each policy parameter P_j was varied a set amount to determine the magnitude and direction of change in system performance.

New base performance levels were formed at different $\underline{X}$ and RSTOR(0) values. Specifically, $\underline{F}(\underline{X}_2,\underline{P}_1^0)$ and $\underline{F}(\underline{X}_3,\underline{P}_1^0)$ were calculated at RSTOR(0), representing changed information quality. Also, $\underline{F}(\underline{X}_1, \underline{P}_1^0)^+$ and $\underline{F}(\underline{X}_1, \underline{P}_1^0)^-$ were computed at increased and decreased crisis levels RSTOR(0)$^+$ and RSTOR(0)$^-$ respectively. Once base values were established, each P_j was again varied a set amount and performance changes noted.

The rationale for this test is that the direction of performance change with varying P_j may be significant when viewed across $\underline{X}$ and RSTOR(0) values. The magnitude of change may or may not be important, depending upon the objective function used. It should be noted that the sensitivity displayed by the P_j is not exactly sensitivity to changes in $\underline{X}$, since the base vector $\underline{P}_1^0$ is used throughout.

Performance Function

Let us examine the objective function used in the above calculations. Recall that Equation 8.1 presents a multiple response problem. A method must be devised to determine when a given system performance is better or worse than or equal to a second performance.

The results recorded in Table 8.4 indicate that of the two system performance variables being used, the number of deaths (TDETH) is much more reliable than total nutritional debt (TNUTD).

Thus, a weighted average performance change will be calculated in order to place more of the decision burden on TDETH. One number is obtained as a measure of system performance. It will be labeled STYNUM.

Equations 8.2 define the weighting function to be used. Note that $STYNUM_{jk}$ represents a weighted percentage change in $\underline{F}$ caused by a change in P_j, at base vector k. Hence, STYNUM is dimensionless. Here, k represents one of the five base options discussed earlier ($\underline{F}(\underline{X}_1,\underline{P}_1^0)$, $\underline{F}(\underline{X}_2,\underline{P}_1^0)$, etc.). At each base, an idea of the degree of sensitivity of $\underline{F}$ to each of the P_j's is obtained. The order of calculations is clear. Each base level $TDBAS_k$ and $TNBAS_k$, as well as w_1 and w_2, must be determined before any sensitivity tests are made. Then a performance sensitivity number is calculated for each parameter and base option.

$$STYNUM_{jk} = w_1 * \frac{(TDETH_{jk} - TDBAS_k)}{TDBAS_k} + w_2 * \frac{(TNUTD_{jk} - TNBAS_k)}{TNBAS_k} \tag{8.2a}$$

$$w_1 + w_2 = 1 \tag{8.2b}$$

where:

STYNUM = system performance sensitivity number (dimensionless)

TDETH = total deaths (persons)

TDBAS = base level of deaths (persons)

TNUTD = total nutritional debt (MT)

TNBAS = base level nutritional debt (MT)

j = index on policy parameters

k = index on base calculations

w_1, w_2 = weighting constants.

Note that no absolute values are used in Equations 8.2 in order to distinguish positive and negative STYNUM. This is potentially important when comparing STYNUM across $\underline{X}$ vectors. Besides sign changes, the size of STYNUM and the size and variance of TDETH and TNUTD may be important decision factors.

One further point should be mentioned. The difference in sizes of the individual P_j's must be taken into account when comparing $STYNUM_j$ values. The increment in P_j for sensitivity testing is defined accordingly. Equation 8.3 shows that the range of acceptable values (from Table 8.2) provides the desired standard. Each paramater varies proportionately with its size.

$$P_{j,test} = P_{j,base} \pm .1 * (P_{j,max} - P_{j,min}) \quad (8.3)$$

where:

$P_{j,test}$ = incremental variation of P

$P_{j,base}$ = member of base vector

$P_{j,max}$ = maximum range limit

$P_{j,min}$ = minimum range limit

j = index on $\underline{P}$.

Initial Optimization Vector

The policy parameter values $P_{j,base}$ are the same for each base. They comprise the $\underline{P}_1^0$ vector and are given in Table 8.5. As described above, one-at-a-time sensitivity tests were conducted, starting with a satisfactory $\underline{P}$ vector obtained from earlier work. Equations 8.2 provided the performance measure, with TDBAS and TNBAS being recalculated each time $\underline{P}$ changed. The weights w_1 and w_2 were assigned values .75

Table 8.5 Policy Parameter Vector $\underline{P}_1^o$ and Preliminary Sensitivity Test Results

Name	Min	Max	10% of Range	$\underline{P}_j^o$	TDETH* TNUTD† STYNUM↑	TDETH* TNUTD† STYNUM ↓
CG24	0.0	15.0	1.5	14.0	1.877 102.0 .076	1.790 98.1 .028
CG25	1.0	5.0	0.4	3.9	1.795 105.4 .051	1.795 101.1 .039
CG27	0.0	25.0	2.5	18.0	1.795 95.9 .025	1.80 106.0 .052
CG30	0.0	15.0	1.5	5.5	1.814 89.7 .015	1.827 99.5 .044
CG32	0.0	12.0	1.2	5.0	1.82 92.2 .023	1.771 94.9 .011
CG35	0.0	0.1	.01	.01	1.796 102.0 .042	1.794 102.0 .041
CG36	0.0	8.0	2.0	0.8	1.851 79.3 .0005	1.810 108.0 .064
CG45	0.0	1.0	0.1	.65	1.787 93.6 .014	1.804 87.6 .004
GDE	0.0	0.1	.01	.02	1.793 96.2 .024	1.797 87.2 .0005
Base ($\underline{X}_1$, $\underline{P}_1^o$) Figures					1.795 87.4 0.0	1.795 87.4 0.0

---

* = measured in million deaths † = measured in 1000 MT

↑ = 10% increase in P_j ↓ = 10% decrease in P_j

and .25 respectively. These constants were derived from the results of Table 8.4.

The decision to stop the manual search for $\underline{P}_1^0$ was based on STYNUM values, using a derivation of common gradient techniques. Once all performance changes were positive, implying worse results away from the base vector, the process stopped. Table 8.5 includes the results of the final set of sensitivity tests, including TDETH, TNUTD, and STYNUM. The tabulated TDETH and TNUTD values show that the stopping criteria insures no test case will be pareto optimal to the base values. That is, both $TDETH_j$ and $TNUTD_j$ cannot be lower than TDBAS and TNBAS, for any parameter P_j.

Additional Base Vectors

$\underline{P}_1^0$ has been determined. The next step is to compute base values $TDBAS_k$ and $TNBAS_k$ for each of the four remaining cases: $\underline{F}(\underline{X}_2,\underline{P}_1^0)$, $\underline{F}(\underline{X}_3,\underline{P}_1^0)$, $\underline{F}(\underline{X}_1,\underline{P}_1^0)^+$, $\underline{F}(\underline{X}_1,\underline{P}_1^0)^-$. The regularly used value for RSTOR(0) has been two million metric tons. This represents an approximate twenty-two percent shortfall in required foodstuffs, a medium level crisis. Tests were conducted with ten percent and twenty-five percent variances in the initial storage level. Results are recorded in Table 8.6. Note the expected worsened death totals with decreased RSTOR(0) and poorer information quality. Also note that performance improves as food supply increases. Nutritional debt figures always act inversely to death totals. One cannot determine from these figures whether nutritional debt is more influenced by changing $\underline{X}$ and RSTOR(0) or by changing death totals. Later tests seem to indicate that allowing policy parameters to vary can help reduce TNUTD totals. The ten

Table 8.6 Base Parameters for Sensitivity Tests

Base	Information Vector	RSTOR (o) (Million MT)	Monrun	Total Deaths (Millions)	Total Nutritional Debt (1000 MT)	STYNUM, Base $\underline{X}_1$, $\underline{P}_1^o$
$(\underline{X}_1, \underline{P}_1^o)^{--}$	Clairvoyant	2.5	1	.9003	93.9	-.355
$(\underline{X}_1, \underline{P}_1^o)^{-}$	Clairvoyant	2.2	1	1.402	102.0	-.122
$(\underline{X}_1, \underline{P}_1^o)$	Clairvoyant	2.0	1	1.795	87.4	0.0
$(\underline{X}_1, \underline{P}_1^o)^{+}$	Clairvoyant	1.8	1	3.114	39.3	.414
$(\underline{X}_1, \underline{P}_1^o)^{++}$	Clairvoyant	1.5	1	5.243	4.37	1.20
$(\underline{X}_2, \underline{P}_1^o)$	Good	2.0	3	3.791 (.49)*	31.3 (13.1)*	.674
$(\underline{X}_3, \underline{P}_1^o)$	Poor	2.0	4	4.661 (.57)*	24.1 (21.0)*	1.02

*Standard deviation.

percent change levels (2.2 and 1.8 million MT) were chosen for further work because they produce results in the same vicinity as 2.0 million. The larger band represents too wide a spread; the credibility of the model may become overtaxed.

Observations

The above approach has several appealing characteristics when no optimization algorithm is available. Only one manual optimization step is needed, instead of the three suggested earlier. And the single optimization takes place at the clairvoyant vector $\underline{X}_1$, where the lack of randomness allows use of MONRUN equal to one. So stochastic error and the number of simulation runs required are both reduced dramatically.

Once the optimization determination is made, the exact number of further required model runs is known. This allows planning for computer expense requirements. The number of runs needed is computed in Equation 8.4. The "2" stands for positive and negative parameter increments; the rest is self-explanatory.

Model use for identifying $\underline{P}_1^0$ can be estimated. Each cycle of tests requires two runs for each parameter plus one base run. The base run can be eliminated if the best result from the previous cycle is used. In the current example, seven test sets were required before Table 8.5 was obtained. Thus, 7 * 18 = 126 model runs were needed. When added to the result from Equation 8.4 (m_2 = 3, m_3 = 4), the overall total becomes 288.

$$NRUN = n * 2 * (m_1 + m_2 + m_3 + r) \qquad (8.4)$$

where:

NRUN = number of sensitivity test runs after $\underline{P}_1^0$ found

n = number of $\underline{P}$ parameters

m_1 - MONRUN at $\underline{X}_1$ (1)

m_2 = MONRUN at $\underline{X}_2$

m_3 = MONRUN at $\underline{X}_3$

r = MONRUN at RSTOR(0).

A third appeal here is that the 288 runs should offer plentiful data about the worth of policy parameters in relation to information quality and crisis level.

Unfortunately, each of the above appeals is flawed. It is true that only one optimization is required, but it is nearly impossible to get close to a true "best" value $\underline{P}_1^0$, since variable interactions are not taken into account. Further, there is no guarantee that the process will converge to a global optimum. It is also true that the number of simulation runs can be estimated fairly closely. But the additional factor of operator time must be considered. To approach a good $\underline{P}$ set quickly, intuition and an understanding of the model are invaluable assets. This is most easily demonstrated when two separate P_j's indicate directions of better performance but their combination greatly worsens objective values. Where does one make the next tests? Operator expereience is crucial.

Results

These flaws are acceptable, especially if no algorithm is available. But an unacceptable flaw in the approach occurs if results obtained are so fuzzy and confusing as to be worthless. Indeed, in this case, the lack of variable interactions, the use of a nonoptimal $\underline{P}$ at

$\underline{X}_2$ and $\underline{X}_3$ and the presence of a fuzzy objective value led to inconsistent outcomes. The complete set of STYNUM results is given in Table 8.7, arranged by base option. Note that the clairvoyant $\underline{F}(\underline{X}_1, \underline{P}_1^0)$ entries match the STYNUM columns of Table 8.5 and the TDBAS and TNDAS figures tie to those from Table 8.6.

What conclusions can be drawn? Several decision criteria can be used. First, examine the direction of the performance change induced by each P_j by studying the positive and negative signs on $STYNUM_j$ values. All clairvoyant $\underline{X}_1$ $STYNUM_j$ values are positive. If such a trend continues across $\underline{X}$, conclude that P_j is not sensitive. Look for a trend across $\underline{X}_2$ and $\underline{X}_3$ columns: positive-negative, negative-positive switches with plus and minus increments. Such a match accompanied by a definite change in magnitude between $\underline{X}_2$ and $\underline{X}_3$ would result from a sensitivity to data quality change. Similar tests could be made across RSTOR(0) values. Sensitivity at such points would represent the effect of crisis level on the ability of P_j to influence performance. Unfortunately, no parameters meet either set of criteria. CG24, CG32, and CG30 are positive at one $\underline{X}$ vector but mixed or negative at the other. CG36 and CG25 are negative at all values, indicating that any change is an improvement. This would seem to indicate the sensitivity of these two parameters. No parameter is consistent in its positive-negative alignment. For the crisis level sensitivity tests, CG24 and CG45 indicate consistent direction of performance improvement. CG36 is positive for reduced RSTOR(0), while GDE is negative for all four quantities, indicating a sensitivity to crisis level change.

A second criterion for determining sensitivity would add a magnitude qualification. Exclude all STYNUM absolute values less than .02

Table 8.7 Sensitivity Number (STYNUM) Results of One-at-a-Time Sensitivity Testing

BASE	$(\underline{X}_1, \underline{P}_1^0)$		$(\underline{X}_2, \underline{P}_1^0)$		$(\underline{X}_3, \underline{P}_1^0)$		$(\underline{X}_1, \underline{P}_1^0)^+$		$(\underline{X}_1, \underline{P}_1^0)^-$	
Parameter	10% ↑	10% ↓	10% ↑	10% ↓	10% ↑	10% ↓	10% ↑	10% ↓	10% ↑	10% ↓
CG24	.0762	.0284	.0249	.0624	-.0922	-.0200	.365	$-.003^*_B$	.069	$-.011^*_B$
CG25	.0515	.0393	$-.0366_B$	-.0700	-.0161*	-.0025*	.010*	$-.003^*_B$	$-.028_B$	.008*
CG27	.0245	.0520	.0539	-.0268	-.0777	.0062*	.0001*	.0006*	$-.083_B$	.010*
CG30	.0147*	.0441	.0113*	-.0385	.1243	.0772	.009*	-.0005*	-.070	.006*
CG32	.0234	.0114*	.0414	.0532	-.0092*	.0118*	$-.043_B$	-.014*	.030	$-.023_B$
CG35	.0421	.0410	.0172*	-.0280	-.0185*	.0679	$-.026_B$	$-.016^*_B$	-038	$-.074_B$
CG36	.0005*	.0644	-.0293	-.0223	-.0683	-.0600	-.006*	$-.030_B$	.003*	.008*
CG45	.0141*	.0041*	-.0208	-.0076*	$-.0390_B$	.0222	$-.031_B$	.002*	$-.016^*_B$	.0004*
GDE	.0242	.0005*	$-.0529_B$	$-.0512_B$	-.0416	.0383	$-.021_B$	-.0001*	-.0002*	-.016*

* = value less than .02
B = Pareto better result, compared to base case

(representing less than a two percent change in system performance). Then once again examine the columns for patterns. Such a decision rule would say that very small values indicate very little sensitivity of performance to the particular P_j. The STYNUM entries less than .02 in Table 8.7 are marked with a "*" in the upper right corner of the entry.

For information quality variation, CG45 is seen to qualify for sensitivity if its insignificant value is excluded. CG32 has only positive values remaining, indicating insensitivity. These judgments are tempered by the fact that both parameters' changes are insignificant in half the tests.

Crisis level variation is more revealing when magnitude is considered. Using the two percent qualification level, parameters CG25, CG45, CG30, CG36, GDE, and CG27 are significant at least half the time. This may indicate that these parameters are not highly influenced by crisis level. CG24 would be judged insensitive, based on significant values.

Pareto criteria can be applied as a secondary consideration. By examining TDETH and TNUTD figures from which STYNUM was calculated, those P_j which produce clearly better results compared to the corresponding base are discovered. These are marked "B" in the lower right corner of the table. Parameter GDE presents a paradox in that movement in either direction improves performance when $\underline{X}_2$ is used. The case for CG45 sensitivity discussed above is strengthened by the identification of pareto better movement. One clearly noticeable item is that policy parameter changes are more likely to cause pareto improvement when crisis level varies than when information quality varies. Of the P_j

variants listed in Table 8.7, 14/36 produced pareto better results for RSTOR(0) changes, as opposed to only 4/36 for $\underline{X}_2$ and $\underline{X}_3$ changes.

Still other rules were considered. The STYNUM figure presents an average evaluation of parameter sensitivity over a set of runs. A possibly more telling piece of information would be the percentage of runs that produced similar positive or negative STYNUM results. Here, again, very few parameters produced solid performances. Most STYNUM averages were indications of majority rule.

The last rule tried was complete elimination of TNUTD from objective calculations. This was done on the grounds that TNUTD varies widely and TDETH would provide a more reliable value. But the data was no more useful than previous work.

The problem here is that we know what STYNUM picture would result for a particular "nice" type of sensitivity. We do not know what sensitivity type is represented by the "un-nice" STYNUM pictures in Table 8.7. Does a positive-negative (or reverse) combination in a column represent a clear case for sensitivity? The available information is not sufficient for accurate prediction. Any decision criteria would have to include outside data sources or qualification judgments.

Parameter Choice

Given all the above reservations on the quality of results here, no solid decisions will be made on the $\underline{P}$ parameters to be used in further optimization work. If absolutely necessary, I would choose the following: CG36, CG25, CG45, GDE, CG24, CG30. My reasoning would be that CG45, CG36, and CG25 appear to be most promising, and CG32 appears to be least significant. CG24 and CG30 are included to insure representation of one variable of each type and equation in the final list.

The problem of confidently reducing the number of parameters and their size limitations has not been solved here. A set of parameters can be guessed at, but the choosing is unreliable and affords little real comparison. No allowance is made at all for reducing the size of the observation space. But a few positive results still obtain from the sensitivity testing exercise.

The objective surface $\underline{F}$ is seen to be very fuzzy, especially where TNUTD is concerned. Planning will have to be done to insure that methods used can handle variability. Because TNUTD varies widely, it is worth examining multiple response methods that reduce to a single objective value.

The worth of a good optimization algorithm is clear. Reliable knowledge of the vectors $\underline{P}_1^0$, $\underline{P}_2^0$, and $\underline{P}_3^0$ would settle the sensitivity question without the drudgery and uncertainty of numerous sensitivity tests. The routine must be able to handle parameter interactions and crisis level changes in addition to the variability problem mentioned above.

An interesting side problem is also presented. Results in Table 8.6 show that a 500,000 MT difference in initial storage RSTOR(0) is roughly comparable to the change in going from best to worst information quality. This tonnage represents a twenty-five percent change in the defined crisis level or approximately eleven percent of the total food requirement. So prediction of the extent of a famine is an important matter. Preliminary results in Table 8.7 indicate that policy parameters may be more able to improve on a poor crisis level than on poor information quality. A more thorough study of such points would greatly aid planners in resource allocation decisions and the use of policy decisions to influence a famine's effects.

The Complex Algorithm

This section describes the use of a computer algorithm to solve Equation 8.1. Again the test design calls for three fixed information quality vectors $\underline{X}_k$, an estimated "best" $\underline{P}_k^o$ for each vector, and a study of differences among $\underline{P}_k^o$'s.

It was noted in previous sections that varying one P_j variable at a time is a slow, cumbersome and contradictory process. Thus, we are looking for a method that allows all policy parameters P_j to vary at the same time, allows for constrained parameters, is cheap but accurate, can be interfaced with a computer simulation, can handle at least nine independent variables, can handle randomness, and can handle the problems of multiple responses and crisis level.

An algorithm has been chosen for use in this chapter that should be able to quickly and easily produce desired results. The Complex algorithm was developed by Box (8). A discussion and FORTRAN coding of the routine are presented by Kuester and Mize (33, Chapter 10). The Complex method was chosen because it has been used previously by the author, is readily available, and is easily adopted to interface with simulation models. It has the further desirable quality that it commonly converges quickly to an optimum area although it is slower to pinpoint exact solutions. This fits the expected stochastic nature of the response surface in this problem. Monte Carlo techniques can be used to help eliminate random errors, and crisis level variation fits nicely into the Monte Carlo methods. A quick, fairly accurate solution is desired, to determine sensitive parameters and gain an understanding of the performance surface. The solution "best" parameter levels are not as important as the determination of sensitivities.

A quick description of Complex follows. REferences to the current problem are interspersed in the commentary.

In the Complex method, a vector of N independent variables contains the $\underline{P}$ parameters and forms one point in the observation space. A total of K points are selected and form a polyhedral complex in N-space. K must be greater than N. One starting point is specified by the user; the rest are randomly selected within the limited defined space. This random selection normally helps assure convergence to a global optimum, if one exists.

The specified starting point must satisfy all implicit and explicit constraints. The explicit constraints are the upper and lower limits for the N parameters. Implicit constraints are algebraic combinations of the parameters that must satisfy predetermined conditions. M is defined as the total number of constraint sets (upper and lower values). Note that in the current case, N equals nine. Since $\underline{X}$ is fixed, there are no explcit constraints on $\underline{X}$ and no implicit constraints on $G(\underline{X})$. Thus, M also equals nine. K is chosen equal to twelve for all test cases here. Although a larger K implies more computation time, it also lessens the chance that the algorithm will become trapped on a ridge or valley of the response contour.

The value of the objective function is calculated at each starting point. This is the interface with the simulation; the model uses the starting point's parameters as inputs and produces the objective function value. The algorithm proceeds with the deletion of the worst point. It is replaced by a new point α times as far from the centroid of the remaining points as the distance of the rejected point from said centroid. The direction of travel is on the line between the replaced point and the centroid. The centroid calculation is given in Equation 8.5, while Equation 8.6 contains the computation of the new point. A value of 1.3 is used for α , as suggested by Kuester and Mize (33).

$$\overline{P}_j = \frac{1}{K-1} * \sum_{\substack{i=1 \\ i \neq 1}}^{K} P_{i,j} \quad j=1,2,\ldots,N \tag{8.5}$$

$$P_j(\text{new}) = \alpha *(\overline{P}_j - P_j(\text{old})) + \overline{P}_j \tag{8.6}$$

where

$\overline{P}_j$ = jth member of centroid of remaining points

$P_{i,j}$ = jth member of point i

$P_j(\text{old})$ = jth member of rejected point

$P_j(\text{new})$ = jth member of prospective replacement point

k = number of points

N = size of vector $\underline{P}$

i,j = indeces on vector $\underline{P}$

α = reflection factor.

The single-valued objective function for the new point is computed by the model. If this is still the worst value, the new point is moved back one-half the distance to the centroid and tested again. This continues until the objective function for the new point is better than one of the other values, and the cycle repeats. One iteration is completed.

Checks are made at each stage. Each new point must satisfy all implicit and explicit constraints. For explicit constraint violations, the new point is moved a small distance, δ , inside the violated limit. In the case of implicit encroachment, the point is moved one-half the distance to the centroid and tested again. Note that the centroid itself will always obey all constraints as long as all original points do.

Covergence is achieved if the objective function at each point falls within β units for α consecutive interactions. β and α are important parameters for indicating the degree of reliability of the algorithm's outputs: $\underline{X}$ and $\underline{P}$ parameter settings and the objective value they produce. Recall that randomness is introduced in the model, and the model computes the performance level (objective value). The simulation is run in a Monte Carlo mode, producing an average objective function value. The parameter MONRUN determines the number of model runs used to compute averaged function values. All of the Complex method parameters (and their employed values) are presented in Table 8.8.

Design Criteria

Several design matters are now discussed before presenting test results. These matters include the objective function used, the inclusion of crisis level in the optimization, and the selection process for starting points.

Performance Function Substitute--PERTOT

Work in the previous section suggested that both $\underline{F}$ relief goals TDETH and TNUTD vary with poor information quality and that TNUTD produces especially unreliable objective results. To combat this, an

Table 8.8 Complex Method
Parameters and Levels Used For Preliminary Testing

PARAMETER	DESCRIPTION	VALUE USED IN CHAPTER 8
α	Reflection factor	1.3
β	Convergence parameter	.001
γ	Convergence parameter	5
δ	Constraint violation correction	.0001
K	Number of points in complex	12
M	Total number of constraint sets (upper and lower limit)	9
N	Number of explicit independent variables	9
Monrun	Number of Monte Carlo runs for each complex point	1 - $\underline{X}_1$ 3 - $\underline{X}_2$ 4 - $\underline{X}_3$

objective proxy has been devised, making use of the theoretical basis of nutritional equalization across population classes. Recall from earlier chapters that four distinct groups are present in the model. The goal of the policy strategy is to spread foodstuffs as evenly as possible across the groups, thereby spreading nutritional losses. Up to a point, weight loss means lowered food requirements, allowing available food to go further. The proposed objective function builds on this, trying to equalize deaths across all classes. Since population totals within groups are unequal, percentage death within a class will be the key statistic. It is desired to keep total percentage death low and to equalize percentages across classes. Equations 8.7 present the calculations.

$$PERAVG = \tfrac{1}{4} * \sum_{i=1}^{4} PERCD_i \qquad (8.7a)$$

$$PERTOT = w_3 * PERAVG + w_4 * \sum_{i=1}^{4} (PERCD_i - PERAVG)^2 \qquad (8.7b)$$

where:

$PERCD_i$ = percentage death in class i (after one year)

PERAVG = average percentage death

PERTOT = objective function value (dimensionless)

w_3, w_4 = weights.

Equation 8.7b provides a weighted sum of the average percentage deaths for all groups and the sum of squared deviations from the average. The average is included to keep total deaths low, and the deviations calculation is to provide equality among classes. The only weight settings used here were with both w_3 and w_4 equal one.

PERTOT was used at this stage for two reasons. First, some sort of single-valued function was needed by the Complex algorithm. TDETH is a logical choice, but minimizing TDETH causes an unacceptable result: TNUTD skyrockets. The equalization theory provides a possible alternative. The second reason is that this preliminary optimization phase provides an excellent testing ground for compromise objective functions such as PERTOT. By examining intermediate algorithm results, one can determine whether minimization of PERTOT will lead to decreased TDETH with a reasonable TNUTD level. Thus, Complex results (Table 8.9) will include PERTOT, TDETH, and TNUTD values. Recall that the goal here is not to minimize $\underline{F}$, but rather to identify sensitive $\underline{P}$ parameters. This goal can be reached with PERTOT. A bonus is possible if the sutstitute objective can serve in Chapter IX as well.

Crisis Level Variability

A second design feature is the inclusion of crisis level variability. To insure a spread in the starting values of RSTOR(0), an explicit calculation is made that ties RSTOR(0) to a set range of values and to the number of simulation runs, MONRUN. For MONRUN equal one, the standard value of RSTOR(0) equal two million metric tons is used. For MONRUN greater than one, iterative calculations increment RSTOR(0), so that initial values range from 1.9 to 2.1 million metric tons. Equations 8.8 were used.

$$DIFF = 2 * 10^5 / (MONRUN-1) \qquad (8.8a)$$

$$RSTOR(0)_0 = 2 * 10^6 - \frac{DIFF * (MONRUN+1)}{2} \qquad (8.8b)$$

$$RSTOR(0)_N = RSTOR(0)_{N-1} + DIFF \quad N=1,2,...MONRUN \qquad (8.8c)$$

where:

DIFF = increment between run values (MT)

MONRUN = number of model runs to be averaged

RSTOR(0) = crisis level proxy = initial rural private storage (MT)

N = index on model runs.

Simple calculations show that for MONRUN equal two, the RSTOR(0) values will be 1.9 and 2.1 million. And for MONRUN equal three, the $RSTOR(0)_N$ will be 1.9, 2.0, and 2.1 million for N=1,2,3. Thus, variability of crisis level is built into the simulation averages. Results can now be expressed as expected outcomes for a given information quality and a food shortfall in the range of twenty to twenty-four percent.

Algorithm Starting Points

The final design feature to be discussed in the use of starting points for the algorithm. Table 8.2 describes the upper and lower limits imposed on the nine P parameters examined in these sensitivity tests. For each of the three X vectors, a starting P point for Complex was picked by taking the midpoint of the allowable range for each parameter. The tests with clairvoyant and good X converged quickly. Second tests were run with off-center starting points. These were chosen by alternately selecting values half-way from the center to the upper and lower limits of the variables. Convergence was achieved close to the first results.

for the fixed poor X vector, convergence did not occur on the first Complex run. A second run was made by constricting P limits and using the new midpoint as a start. The intent of the further constraint was to limit the space over which optimization was conducted. The new limits were based on results of the first run. Again, convergence was not obtained. In both cases, the algorithm bogged down near a centroid that produced consistently bad results. Evidently, the randomness in the model produced a few inaccurate points which unduly influenced the centroid. The problem was only minor, though, since the range of values from the best ending vectors is reasonably narrow.

Optimization Results

Table 8.9 presents the results from the above experiments. The algorithm provides details at each iteration. Thus, the figures in Table 8.9 are averages of the best $\underline{P}$ vectors over the course of two runs at each $\underline{X}$ vector. Best refers to minimum PERTOT. In the clairvoyant $\underline{X}$ cases, convergence was so good that only an average of the two best $\underline{P}$'s and the centroid is given. For good and poor $\underline{X}$, the range of the best values is listed along with the average. The centroid is not included in poor $\underline{X}$ figures. The intent is to provide as broad a picture of the true results as possible, so that decisions reached on policy sensitivity are well-informed.

Policy parameter settings and objective results are given in Table 8.9. Following them is a set of optimization run-time parameters. Iterations refers to algorithm iterations. MONRUN is the familiar number of Monte Carlo simulation runs averaged for each objective function calculation. Model runs refers to the total number of model simulation cycles made. It is affected by MONRUN and by the need for calculation of repeated prospective better points at each algorithm iteration. Time refers to CPU seconds on a Control Data 6500. And the convergence entry repeats the results discussed above.

Table 8.9 Optimization Algorithm
Results at Three Different Information Quality Vectors

PARAMETER/ OUTPUT	CLAIRVOYANT $\underline{X}_1$	GOOD* $\underline{X}_2$	POOR* $\underline{X}_3$
CG24	4.75	0.5-1.65 1.15	1.46-2.59 1.92
CG25	2.69	2.23-4.13 3.01	3.08-3.83 3.41
CG27	6.58	8.17-11.77 10.03	2.95-5.68 3.97
CG30	6.97	16.85-23.47 19.84	9.96-17.06 12.80
CG32	3.33	2.93-4.56 3.57	5.32-7.95 7.04
CG35	.057	.024-.049 .039	.057-.074 .061
CG36	1.26	1.47-1.77 1.65	.87-1.50 1.21
CG45	.82	.46-.835 .69	.482-.602 .52
GDE	2.69	2.23-4.13 3.01	3.08-3.83 3.41
PERTOT	.053	.053 (.016)	.074 (.016)
TDETH (Millions)	1.76	1.92 (.65)	2.76 (.64)
TNUTD (100 MT)	102.5	93.5 (22.6)	92.1 (32.0)
Number of Model runs	87	222	224
CPU Time (SEC)	525	1150	1200
Convergence	Yes	Yes	No

* = Spread and average of runs given

Table 8.9 reveals several interesting facts about famine relief policy parameters. Four parameters vary little with information quality: consumption controls GDE and CG35, nutritional debt control CG36, and rural private storage control CG45. The first three are quite evident; their spreads either overlap or are consistently close to a starting value. CG45 was excluded from further work because the spread of values does not indicate a large change, and parameter CG30 is to be included. Note however, that the average figures indicate a pattern; CG45 decreases with information quality. In retrospect, it would have been a good idea to look further at this variable because the pattern has a practical interpretation. The early acquisition rate (see Equation 4.3) should be decreased if information quality degrades. This would imply that a looser control is needed when only poor data are available.

Two parameters provide clear indications of good relief policy. Crisis-transport-increase parameter CG25 and nutritional debt control CG32 show a consistent pattern for dealing with changes in information quality. CG25 increases as data quality erodes. This would mean that the emergency transport between rural and urban storage should be stepped up when information quality is poor. Numerically, the rate should be increased from three times normal with good data to 3.5 with poor data. Evidently such an increase would help to insure enough urban storage when the actual situation is not well known.

As information quality decreases, parameter CG32 increases. CG32 represents the nutritional debt control in the government sales equation. It is intended to help provide equality between the rich and poor urban classes. The Complex results indicate that control should be tightened as nutritional status data are less reliable. In earlier model work, such control tightening with poor information often led to large oscillations in urban class nutritional debt. Poor decisions made from poor data had poor results. A looser control helped avoid such cases by decreasing the impact of any data. Something has occurred to alter earlier results. Perhaps the other parameters contributing to government sales decisions (see Equations 2.14 and minimum sales proportion discussion in Chapter 3) have softened the effect of a tight CG32. This is left as an area of further exploration.

The remaining three variables are nutrition control CG27, consumption control CG24, and storage control CG30. Each of these varies widely with X and so is included according to the sensitivity definition explained earlier. No explainable pattern is discernable in the numerical results noted. In each case the preferred value increases then decreases with information quality or vice-versa. Such a relationship would be strange, but possible. It is also possible that the objective function is insensitive to changes in these parameters, and they vary for some unknown reason. Another possibility is that MONRUN is too small, resulting in large error terms. CG27 and CG30 have especially large spreads. But they cannot be ruled insensitive at this point and will be included in further work.

Table 8.10 has been constructed from the above remarks and Table 8.9. Four policy parameters are ruled insensitive; their fixed values for further work are given. The remaining five are to be included in Chapter IX studies. Note a pleasant result of this optimization approach. The limits on parameter values can be reduced from their original status in Table 8.2. The new constraints follow from the best

Table 8.10A Policy Parameters to Be Carried to Final Optimization Stage

PARAMETER	DESCRIPTION	MINIMUM	MAXIMUM
CG24	Consumption control, emergency food equation	0.0	6.0
CG25	Crisis transport rate-increase parameter	2.0	5.0
CG27	Nutritional debt control, emergency food equation	0.0	12.0
CG30	Rural private storage, acquisitions equation	5.0	25.0
CG32	Nutritional debt control, sales equation	2.0	10.0

Table 8.10B Fixed Policy Parameter Values

PARAMETER	DESCRIPTION	VALUE
CG35	Consumption control, acquisition equation	.05
CG36	Nutritional debt control, acquisitions equation	1.5
CG45	Rural private storage control, early acquisitions equation	.65
GDE	Consumption control, sales equation	.08

value spreads contained in Table 8.9. Since the three X vectors cover the range of possible information quality, the spreads plus small insurance margins should span the likely optimal observation space. This reduction of the search space should speed further optimizations. One note of caution does come from the Complex process. An extremely fuzzy surface places limits on the ability of the algorithm to converge. In such cases, constraint reductions will not make estimated results any more reliable.

One additional aid provided by Complex that was not extensively used here is the ability to follow the course of the polyhedron formed by the K-point "complex." Quantitative data are available at each iteration, including new point choice, variability of the objective value and rejected new points. Study of such data will be used in the next chapter to determine reliability of results and help pinpoint "best" parameter values.

Conclusion and Summary

Several helpful results can be drawn concerning the use of optimization algorithms, results of fuzziness in the model, relative importance of policy choice and optimization, and particular policy parameter settings.

The worth of a computer algorithm is evident. Results and choices are much clearer than with one-at-at-time sensitivity testing. The amount of work required is less when a "canned" algorithm is available, and the amount of computer time required may be smaller also. Here, the algorithm approach required roughly four times as many model runs, if preliminary work necessary for the standard sensitivity testing is excluded. Preliminaries in the standard case would include setting tight parameter limits and obtaining a good starting P vector. Additional runs would be needed if P sensitivity questions and observation space reduction were to be resolved through the one-at-a-time variability process. Note that guesstimates at the end of the standard sensitivity testing section agree with Table 8.10 on only four of nine parameters.

The Complex algorithm has several desirable features. It is easy to use, allows for randomness and constraints, interfaces with the model, and converges to a general area rather quickly. It also provides data for possible reduction of the range of each tested parameter.

When faced with the problem of no available algorithm, it may be worthwhile in the long run to develop the necessary code rather than rely on manual searches. Some form of regression or factorial design would also probably be better than the technique outlined in this chapter. The only real advantage of using the approach here is that one becomes very familiar with the intricacies of the model's being used.

The nature of the performance function surface for F is fairly clear. The two objective values TDETH and TNUTD are fuzzy, especially nutritional debt, TNUTD. Contributing to the variability in the surfaces is the inverse relationship present between the two objectives. This also leads to the conclusion that TDETH cannot be used as a single goal, since minimization of total deaths leads to huge, unacceptable levels of nutritional debt.

The use of substitute objective function PERTOT worked well here. PERTOT was defined to take advantage of the policy strategy's being used and succeeded in keeping both TDETH and TNUTD at low levels. Table

8.9 presents average values for PERTOT, TDETH, and TNUTD over the best policy points at each of the fixed X vectors.

The results displayed in Table 8.9 and 8.10 offer several interesting conclusions about the relationship of policy parameters and information quality in the current model. Optimal consumption policy parameters are quite insensitive to information quality change. Only CG24, the parameter in the emergency food aid equation, shows variance with X. This could indicate that consumption policies do not greatly affect system performance, or it may be that the effect was overshadowed in these tests by the predominance of nutritional debt and storage policies and data measurement.

Three particular situations are candidates for further study. Results indicate that as information quality is reduced, the following policy adjustments are helpful: increase the emergency rural-to-urban transport rate, increase the nutritional debt decision control in government sales, and decrease the early government acquisitions rate.

It was mentioned in the chapter introduction that policy parameters were to be the focus here. This was done because information quality parameters had been set previously, in Chapters V and VI. In general, an approach similar to the algorithm method in the previous section could be used to reduce the number of information quality parameters to be used in final optimization work. The problem would be to determine the sensitivity of the objective function F to the individual X parameters. The insensitive X members could be identified by the following process. Fix policy parameters F and use Complex, with X's varying at two or three different cost constraint levels. Recall that G(X) must be used, necessitating implicit constraints in Complex. At each solution, simple one-at-a-time sensitivity tests will indicate the $\underline{X}$ parameters with little effect on performance, as long as a factor is included to offset the difference in parameter sizes.

Summary

The reduction of the observation space is a good practical goal in any optimization problem, especially when the number of variables is quite large. A general approach is discussed here, where an examination of desired optimization results leads to the identification of the particular sensitivities that certain variables should possess if they are to be included in the optimization. Sensitivity tests can then be designed to uncover the desired traits. In the current problem, sensitivity to information quality changes told which policy parameters to use. Objective function sensitivity to information quality changes would tell which information parameters to use.

The advantage of a computer algorithm is clearly seen, as results and choices are much more reliable than under a one-at-a-time sensitivity test pattern. The Complex algorithm with a substitute objective based on nutrition equalization proved to be a useful optimization tool. A discussion of a possible approach in the event of no available computer algorithm showed that results in such a case are largely unsatisfactory.

CHAPTER IX

SIMULATION OPTIMIZATION

Much ground has been covered in Chapter VIII. Parameter limitation preliminaries have been completed and the factor vectors $\underline{X}$ and $\underline{P}$ are chosen. The form and type of the objective response surface have been examined. The optimization problem definition has been narrowed. The simulation computer model is ready. The remaining task is to pick a routine and optimize.

Let us first reexamine the purposes of the planned optimization since they will determine the direction of research. Clearly, one of the main goals is to identify "best" parameter levels for $\underline{X}$ and $\underline{P}$ at several different cost constraints. Not only must the parameters be determined, but the associated chosen information system alternatives must be described. And, for each set of "best" parameters, the expected performance level and the degree of confidence in results must be noted.

As the optimization proceeds, it is hoped that some understanding can be gained of the relative importance of the individual information quality parameters and the system components that the parameters represent. Such knowledge would be extremely useful in assigning priorities to resource expenditure when the allocation for the information system is limited. Similarly, the relative importance of $\underline{P}$ policy parameters should be studied, as well as the relationships between $\underline{X}$ and $\underline{P}$.

One final goal is the generalization of results from this study. For actual famine relief planning, a list of real-world variables with suggested monitoring statistics would be invaluable. Chapter I has outlined a perspective on the use of information and data collection.

The chapter follows the development of the optimization research. The first section finalizes the criteria for selection of an algorithm, both from a standard optimization point of view and from the perspective of the current study. Then, the actual selection process is discussed. The third section outlines the experimental design to be used, followed by results and analyses. The final section serves as a summary and conclusion.

The Optimization Problem and Solution Considerations

The problem to be solved is stated in Equation 9.1. In attacking this problem, the tools to use depend a great deal on the nature of $\underline{F}$, G, $\underline{X}$, $\underline{P}$, and the constraints C, $\underline{D}_1$, $\underline{D}_2$, $\underline{E}_1$ and $\underline{E}_2$. Many factors influence the choice of an optimization algorithm. These factors are grouped here into three categories based on their relationship to the overall problem.

$$\text{Minimize } \underline{F}(\underline{X},\underline{P}) \tag{9.1}$$

$$\text{subject to: } G(\underline{X}) \leq C$$

$$\underline{D}_1 \leq \underline{X} \leq \underline{D}_2$$

$$\underline{E}_1 \leq \underline{P} \leq \underline{E}_2$$

where:

$\underline{F}$ = system performance vector (F_1=total deaths, TDETH; F_2 = total nutritional debt, TNUTD)

G = cost function (monetary unit)

$\underline{X}$ = information quality vector (sampling frequency, measurement error, time lag)

$\underline{P}$ = policy parameter vector (rates and triggers)

$\underline{D}_1, \underline{D}_2, \underline{E}_1, \underline{E}_2$ = parameter constraints

C = budgetary constraints

The first group of criteria consists of common theoretical optimization difficulties present in Equation 9.1. The description of each item in this group will center on optimal approaches to solving the difficulty and will identify the course deemed most suitable for the current simulation and hypothetical country. The second group deals with considerations introduced by the nature of famine relief information system design and by the current approach. Most of these have been mentioned in previous chapters and are included here to help tie the theorietical optimization technique to this study. The third and final group is a set of specific decision criteria normally used when choosing a particular algorithm. Lists of such criteria are available for application of algorithms to simulation models (59). The set presented here results from an adaptation of such lists to the current problem.

Theoretical Optimization Difficulties

The presence of constraints on $\underline{X}$, $\underline{P}$, and G favors a constrained optimization routine. The only contrary situation occurs when the search is guaranteed to stay within limits by the nature of the solution. But given the fuzzy flat response surface deduced in the previous chapter, such a case is unlikely.

Two types of constraints are evident. First there are limits on individual parameter values. Recall from Chapter VIII that definitions of some $\underline{X}$ and $\underline{P}$ parameters lead to obvious limitations, and preliminary work with the simulation model helps to sharpen and reduce these limits. A comparison of Tables 8.2 and 8.10 reveals the parameters and limits used here. The constraint on G represents a functional constraint on combinations of $\underline{X}$ and $\underline{P}$ parameters. As in most areas where a cost constraint holds, when one splurges on X_1, one has to reduce expenditures on X_2.

A second theoretical problem to be faced is that the response $\underline{F}$ is generated by a stochastic model, implying there exists variability in $\underline{F}$. A non-exact solution implies that statistical methods are needed to handle the problem. The so-called Monte Carlo techniques are commonly used. Mentioned in Chapters IV and VII, these involve multiple simulation runs for fixed $\underline{X}$ and $\underline{P}$ vectors in order to obtain average output values. The obvious reason for use of "average" results is that uncommon occurrences can lead to improper conclusions. To be relevant, results must be couched in terms of expected or likely outcomes. The goal of any statistical design is to extract as much information as possible from the experiments done (29). Each model run's results can also be extracted in order to construct histogram displays of model results. This would be important in avoiding skewed performance results whose importance may be masked by the average.

The problem where the least amount of research has been done is that of how to deal with an objective or goal vector of more than one variable. Many routines and algorithms exist for problems of only one response, but more than one presents special difficulties. The fact that $\underline{F}$ has more than one objective leads to the classical problem of trying to improve one objective without harming another. This type of condition is commonly called a pareto optimality problem after the economist who suggested criteria for "pareto" optimality. Multiple responses lead to multiple (in fact, infinite) solutions where no mutually advantageous objective improvement is possible.

Note that a computer algorithm cannot make judgments. It can only proceed along well-defined, albeit complicated, paths. Thus, multiple response systems need to have an explicit tie defined between values and algorithm processing. Some approaches deal specifically with individual values and opinions (16).

One general solution method is to form a single objective by attaching weights to the distinct responses of the original problem. The weights correspond to value attached through questionnaires, opinion polls, discussions with decision makers, etc. A wide range of solutions is possible by varying weight structures to allow inspection of relative value implications. Recall that a weighting function is used to define the sensitivity number of Chapter VIII (see Equations 8.2). A second common approach is to designate one response as the most important and relegate others to a constraint role. The problem is changed from optimizing $\underline{F} = (F_1, F_2)$ to optimizing F_1 provided F_2 stays within acceptable limits.

There are several extant papers on multiple response solution algorithms, with such varied method titles as Sensitivity Function (51), Proper Equality Constraints (34), and Goal Attainment Method (19).

These papers all present theoretical mathematical formulations and do not discuss application to simulation models. Montgomery and Bettencourt (47) have proposed an algorithm for handling multiple objectives in simulations. Their test case used only two input variables and involved considerable on-line input from decision makers. This is clearly an area where further research is needed.

Famine Relief and Approach Difficulties

A very important factor to be included in any analysis of famine relief will be the expected crisis level. There is a natural tie-in to the current approach, although it is not directly stated in the problem formulation. It has been noted that statistical methods are needed to handle the built-in stochastic nature of information quality. Crisis level is another unknown quantity that can be handled by a Monte Carlo scheme. Recall from Chapter VII that the variable RSTOR(0), the initial rural private storage level, is functioning as a proxy for crisis level. By varying RSTOR(0) according to a regular distribution, model outputs can be interpreted as likely results for a given range of crisis. This scheme was applied in Chapter VIII (see Equations 8.8).

The overall approach of this study places heavy emphasis on the use of a computer simulation. It should be noted that model intricacies can be easily obscured in an optimization process keyed on one or a few objectives. That is, the optimum (optima) chosen may occur because of some unacceptable modeling quirk. Examination of several output variables in the region of the optimum should indicate possible need for further model development.

Care must be taken to explicitly state value judgments being used in evaluation and interpretation of results. The objectives to be used must be humanitarian; famine relief is a humanitarian activity. Model outputs cannot be taken as absolute because of human factors; the problem is different from minimizing water leakage or other mechanical and physical systems. By "solving" Equation 9.1, it is very likely that a value is implicitly assigned to human life.

A project management issue that must be faced is the importance of $\underline{X}$ and $\underline{P}$, information quality and policy parameters, compared to overall strategy choices. Earlier model results show that a policy of "equalization" reduces the death total resulting from price control policy by more than two-thirds. It is unlikely that any optimization routine will lead to such marked improvement. Note that to pursue a high-powered optimization course on a poorly constructed policy base would be unwise. It is hoped that the results of this chapter's work will reveal the relative worth of the optimization stage compared to the strategy design phase.

The cost vector $G(\underline{X})$ requires substantial off-line analysis, as explained in Chapter V. A unique information system definition for each $\underline{X}$ vector is required beforehand to insure results that make real-world sense. The solution set for Equation 9.1 will be particular $\underline{X}$ and $\underline{P}$ vectors. The chosen vectors should be such that constraints $\underline{D}_i$ and $\underline{E}_i$ are satisfied and the information quality $\underline{X}$ automatically determines information system characteristics and choice. Thus, the need for a unique system for each $\underline{X}$. It is unclear which is likely to be more difficult, determining the G function (off-line) or completing the optimization process. Certainly both will contribute considerable insight to information system development. Real-world data and experience would be most helpful.

Algorithm Choice Criteria

The following items are mentioned as aids in comparing specific optimization methods. Two major considerations exist: the type of problem and the nature of the algorithm. In examining the type of problem, the number and range of the independent variables is important. In the current study, this would be the size and parameter limits on X and P. Smith (59) tests cases of thirty and 120 controllable factors, so there is some hope of solution for very large models.

The nature of the response surface or objective function to be encountered affects algorithm choice. Concave or convex surfaces are easy to work with. The presence of variability, ridges, multiple peaks or plateaus requires more sophisticated handling. A very important criterion involves the information desired from the optimization and the likelihood that a given algorithm will supply such data. It may be desirable to "build" a picture of the response surface by creating a function to estimate the simulation model. Such a function would be useful for regression analysis. On the other hand, the goal of optimization may be to obtain best value solutions, which only require one or a few function values. The accuracy of solution is also important, whether an exact point is required or whether a solution "region" is desired.

The nature of the algorithm should cover the above items; it must handle parameter size, variability, and output requirements as needed by the problem. Other factors are also important. The ease of use of the model should be considered: the availability of programs, adaptability to a particular machine and model, and costs involved. Costs include not only straight monetary costs for purchases and salaries, but also the time costs for planning, programming, computer operations, model run requirements, and results anslysis. Other resources necessary to prepare reports and communicate results may vary by algorithm, the entire system should be examined to determine the crucial interfaces for algorithm choice.

Alternative Solution Methods

The intent of this section is to explore optimization routines that were examined for use in the current study. Let us first describe the state of research at the end of Chapter VIII, as it relates to the optimization process. A single-valued weighting function has been tested that captures the flavor of both objective responses and relates to policy structure. A set of $\underline{X}$ and $\underline{P}$ parameters has been defined, as has the function $G(\underline{X})$. All that remains is to settle upon the form of objective $\underline{F}$ to use, values for cost constraint C, and the algorithm. Constraint C values can be easily calculated from data in the model. The algorithm choice is the subject of this section. But, first, a decision must be made on the nature of $\underline{F}$.

Single Response Optimization

Only single-response optimization techniques will be examined here. As mentioned in the previous section, little work has been done with multiple response in large models; a substantial effort would be required to adapt and test such techniques on the current model. Also, work in the last chapter showed the sizeable variability of total death (TDETH) and total nutritional debt (TNUTD) objectives. Thus, a concerted effort at this point to work with multiple response techniques would be misplaced and beyond the scope of the current study. The weighted average PERTOT, defined in Equations 8.7 (and repeated in Equations 9.2) will be used as the objective function in this chapter. It combines TDETH and TNUTD into one value and approximates a multiple optimization. The weights w_3 and w_4 can be used to alter the mix between TDETH and TNUTD; only values $w_3 = w_4 = 1$ will be used here. The revised form of optimization is given here as Equation 9.3. One further note on optimization work, a numerical solution technique is needed. The classical problem involving a vanishing first derivative is important only as it is used by an algorithm to determine a stopping point.

$$PERAVG(\underline{X},\underline{P}) = 1/4 * \sum_{j=1}^{4} PERCD_i\ (\underline{X},\underline{P}) \qquad (9.2a)$$

$$PERTOT(\underline{X},\underline{P}) = w_3 * PERAVG(\underline{X},\underline{P}) + w_4 * \sum_{i=1}^{4} (PERCD_i(\underline{X},\underline{P}) - PERAVG(\underline{X},\underline{P}))^2 \qquad (9.2b)$$

$$\text{minimize } PERTOT(\underline{X},\underline{P}) \qquad (9.3)$$

$$\text{subject to: } G(\underline{X}) \leq C$$

$$\underline{D}_1 \leq \underline{X} \leq \underline{D}_2$$

$$\underline{E}_1 \leq \underline{P} \leq \underline{E}_2$$

where:

PERCD	= percentage deaths by class (after one year)
$\underline{X}$	= information quality vector
$\underline{P}$	= policy parameter vector
PERAVG	= average percentage deaths
PERTOT	= objective function value (dimensionless)
w_3, w_4	= weighting values

$G, C, \underline{D}_1, \underline{D}_2, \underline{E}_1, \underline{E}_2$ = as in Equation 9.1

i = index on population classes.

Two general optimization techniques are discernable. The difference lies in the function that the algorithm searches. The first method would construct a function $S(\underline{X},\underline{P})$ covering the entire space on $\underline{X}$ and $\underline{P}$. $S(\underline{X},\underline{P})$ would be the resulting equation from a regression utilizing $\underline{X}$ and $\underline{P}$ as input variables and model outputs PERTOT or TDETH or TNUTD as the output variable. Then an optimization process would be run on the function S. The second method deals with the simulation directly, searching over model-generated points on the response surface.

Regression Surface

Running a regression algorithm on the whole vector space has several appealing features. The resulting equation, or metamodel, would allow considerable testing without further model runs (28). Constraints on $\underline{X}$ and $\underline{P}$ can be handled by careful selection of data points. Using selected points and model results as inputs, a regression has much built-in statistical analysis. The S function developed allows a look at the variability and significance of parameters and parameter interactions, plus the sensitivity of the surface to individual parameters. Further, a separate function can be generated for each objective value or combination of values.

Other factors weigh against the use of a regression analysis. The function is a further step removed from the real world. Just as real-world intricacies are missed by the model, so are model intricacies missed by the function. This is especially true when a fuzzy, flat surface exists, such as PERTOT($\underline{X}$,$\underline{P}$), TDETH($\underline{X}$,$\underline{P}$) or TNUTD($\underline{X}$,$\underline{P}$). A regression involves a two-step process. On developing function S, parameter sensitivities and function relibility are deduced. But an additional optimization step is required to minimize values over the space of $\underline{X}$ and $\underline{P}$. It is true that this optimization should be easier over the function S than when using the model. But two separate algorithms are still required, in a situation where highly developed programs may be hard to find.

Search Algorithms

Three examples of search algorithms using the model itself are presented next: the Complex algorithm discussed in Chapter VIII, the Powell algorithm (33, Chapter 10) and a response-surface methodology adaptation developed by Smith (60). Recall that the Complex method operates with a set or "complex" of points in the factor space. The worst point, in terms of objective value, is rejected and replaced by a better factor set on the far side of the centroid of remaining complex points. Only one point is replaced at each iteration. The Powell and Smith methods identify a small subspace and do calculations within the subspace at each iteration. The purpose of the calculations in each case is to identify the direction of most improved movement on the surface. Powell develops a quadratic surface at each stage and moves in the direction of the gradient. Smith has a more sophisticated technique whereby a first-order equation is initially computed using experimental design methods. A test is run to determine the adequacy of the equation; a second-order approximation is developed if the first-order is not satisfactory. The search continues in the projected direction of steepest descent.

Complex and Powell are often used in tandem because of their complimentary convergence properties. Complex tends to move quickly to an optimal area, but bogs down in final stages. Powell converges quickly near the optimum. So using Complex, then Powell is a reasonable approach. Unfortunately the Powell algorithm cannot handle constraints, so its usefulness may be negligible. The Smith routine appears to be quite powerful but its availablity is limited.

Smith has done research comparing algorithms very similar to the Complex and Smith methods discussed above, as well as a one-point-at-a-time technique (59). In comparing the use of a Complex-like routine to Smith's response surface method, the conclusions are drawn that each performs well and is much better than any single factor search. A slight advantage is given to the response surface technique because the direction of search is more direct. However, it was generally true that the Complex algorithm required fewer total model runs. Both routines are for single-valued objectives and can handle the optimization requirements discussed above.

Convenience was a major factor in the final choice of a computer algorithm. The Complex program is readily available. It was able to handle the nine variables, with constraints, in Chapter VIII tests, and its nature is well-suited to the fuzzy surface PERTOT($\underline{X}$,$\underline{P}$). Additionally, the results required at this point must be generally accurate, not pinpointed. Note that hypothetical data permits a study of parameter trends only. Exact answers with inexact inputs are illogical. Complex will suffice to provide the desirable pieces of information discussed in the introduction to this chapter. The algorithm generates enough data to compute a cost versus performance graph, reasonable "best" alternatives at different cost levels, and, when run in a Monte Carlo mode, degrees of confidence in results.

Increased accuracy expected from the response surface methodlogy of Smith is somewhat nullified in the current problem by the extremely variable surface. Also, the importance of policy strategy makes extremely accurate optimization a secondary priority. The Powell method is rejected because it does not handle constraints. With the narrowed limits provided by Chapter VIII research, an unconstrained routine is undesirable. The main advantage of Powell is its quick convergence near an optimum. Again, superior accuracy is not needed here.

Optimization Plan

The ground work for this section has been laid in the previous chapter. Since the Complex algorithm will be used and the problem is largely the same, much of the discussion of optimization problems and model peculiarities from Chapter 8 also applies here.

Optimization Constraints

Equation 9.3 presents the problem to be solved. The objective PERTOT is defined in Equations 9.2. The independent variables $\underline{X}$ and $\underline{P}$ have been defined and limited. Table 9.1 presents each factor along with the constraint vectors $\underline{D}_1$,$\underline{D}_2$,$\underline{E}_1$ and $\underline{E}_2$. Note that Tables 8.3 and 8.10a have been combined to form Table 9.1. Cost formula G($\underline{X}$) in the problem statement has been developed in Chapter 5.

One item will be included in the optimization that is not

Table 9.1 Independent Variable Vectors $\underline{X}$ and $\underline{P}$ With Associated Constraint Vectors $\underline{D}_1$, $\underline{D}_2$, $\underline{E}_1$, $\underline{E}_2$

$\underline{X}$ VARIABLE	DESCRIPTION	MIN (D_1)	MAX (D_2)
SDND	Standard error, nutritional debt	.0005	.002
SDRC	Standard error, consumption	.05	.2
SDRS	Standard error, rural private storage	.05	.2
SAMPT	Sampling interval, nutritional debt	.02	.08
SMPRC	Sampling interval, consumption	.02	.08
SMPRS	Sampling interval, rural private storage	.02	.08
DELD	Information reporting delay	.01	.04
CG29	β parameter, consumption α-β tracker	0.0	1.0

$\underline{P}$ VARIABLE	DESCRIPTION	MIN (E_1)	MAX (E_2)
CG24	Consumption control, emergency food equation	0.0	6.0
CG25	Crisis transpor+increase parameter	2.0	5.0
CG27	Nutritional debt control, emergency food	0.0	12.0
CG30	Rural private storage control, early acquisition	5.0	25.0
CG32	Nutritional debt control, sales equation	2.0	10.0

expressly stated in Equation 9.3. A varying crisis level will be included to simulate the uncertainty in evaluating the extent of a famine. As in Chapter VIII, the variable RSTOR(0) will be assigned staggered starting values at each call to the model by the Complex routine. The details are presented in Equations 8.8.

Complex has been chosen as the algorithm to proceed with. Given the above definitions, the experimental design problem has only two remaining issues: the values to be used for the budget constraint C and the run parameters, including number of cycles through the Complex method. The objective in setting the C levels is to obtain a distinguishable range of performance versus cost results.

Two factors were most helpful in deciding on the cost constraint levels to employ. The first was the establishment of "benchmark" cases marking upper and lower limits on expected costs. The second was simply the use of several experimental computer runs.

Given the limit vectors $\underline{D}_1$ and $\underline{D}_2$, maximum and minimum costs can be determined by applying the equations of Chapter V. There are several constants and parameter values which must be defined, and Appendix A provides a discussion of the translation of the cost chapter's theoretical formulas to an acceptable numerical model. A few calculations using the formulas of Appendix A show that $G(\underline{X})$ can vary between 120 million and 960 million won. (The model conversion rate is four hundred won equal one dollar.)

Model runs showed that C=155 million won would be a good lower limit on the budget. An upper limit will be provided by putting no explicit constraint on G. Of course, G is uniquely determined by $\underline{X}$, so the constraint vector $\underline{D}_2$ sets an explicit limitation on costs.

Additional model runs showed very little difference in performance for G values above 500 million won. Thus three intermediate budget levels were chosen, in addition to the two limiting cases: 400 million, 300 million and 200 million won.

A third cost benchmark was also available. The price control policy mentioned in Chapter II provides an additional upper limit. A Complex algorithm optimization was made, using several price control variables as the independent factors and PERTOT as the objective.* The best result saw over nine million deaths (TDETH) and negative nutritional debt (TNUTD). TNUTD was low because many people died quickly in the simulation, leaving fewer citizens to share the available food. The price control results will be used only as benchmarks, indicators of a worst possible case.

A note on the use of the price control benchmark is in order here. A fairer test would have incorporated two modeling changes. First, the objective should have been some other combination of total deaths (TDETH) and nutritional debt (TNUTD). Recall that PERTOT was designed specifically to take advantage of the equalization policy. Given the negative final value for TNUTD in the price control test, a logical objective would be a single variable, TDETH. A second modeling change would involve the variables being sampled. Price control policy decisions would not be based on nutritional or consumption variables. Rather, market prices, storage information and price change data would be the desired indicators. Of course, such a change would mean a different information system from that described

*The price control variables used were CG6, CGP, CG3, C65, TRUNDO, TPUNDI. See Chapter II and Appendix B for detailed equations.

in Chapter VI and would require substantial additional effort. The estimate derived here is meant only as a gross upper bound and is very likely overstated.

A combined view of the equalization policy and price control policy benchmarks provides a validation point for the computer model. The range of crisis levels used in the current experiments accounts for a percentage shortfall of food between eighteen and twenty-six percent. Based on previous tests of the model, percentage survival should be greater under the equalization policy than under price control, for the tested range of percentage shortfall (39). This result is affirmed in the relative performances of the benchmarks in Table 10.1

Complex Algoritim Parameters

Many of the parameters needed by the Complex algorithm have already been implicitly chosen. The number of variables in $\underline{X}$ and $\underline{P}$ and standard practice algorithm values account for all but the convergence factors and the number of Monte Carlo runs at each Complex point. A definition for each Complex parameter and the value used in the final optimization stage is given in Table 9.2. (A more thorough description of the parameters is given in the discussion of Table 8.8.) Note that parameters β, α and MONRUN are multi-valued, since they vary with the cost constraint employed.

A general pattern was followed in conducting optimization runs at the various budget constraints. A non-stochastic trial optimization was made with MONRUN equal one, β equal .005 and α equal 8. The starting point was picked at a point known to be within the implicit

Table 9.2 Complex Algorithm Parameters for Final Optimization

PARAMETER	DESCRIPTION	VALUE IN CHAPTER 9
α	Reflection factor	1.3
β	Convergence parameter	Trial - .005 Later - .001
γ	Convergence parameter	8 or 12
δ	Constraint violation correction	.0001
K	Points in complex	16
N	Number explicit independent variables	13
M	Total number constraint sets	14
Monrun	Monte Carlo runs per point	Trial - 1 Later - 3
C	Budget constraint	155 million 200 " " 300 " " 400 " " Unconstrained

cost constraint. For the largest three values of C, this point was the centroid of $<D_1, E_1>$ and $<D_2, E_2>$. The main purpose of the MONRUN equals one test was to identify $\underline{P}$ starting values.

A second optimization was done, using the best overall point resulting from the trial and increasing MONRUN to three to allow a more detailed statistical study. Data from the first two runs were used to supply a third stage with restricted bounds on $\underline{X}$ and $\underline{P}$. This limiting of the search space allowed quicker convergence. MONRUN was again set to three. The convergence criteria β and α were also strengthened.

It should be noted that better convergence properties would be expected at higher budget levels, since the sampling error decreases with increased fiscal support. And, in fact, for the largest two constraints, step two was bypassed since convergence came so quickly on the first trial. A fixed computer time cost limit was used to determine convergence; the algorithm was alloted a specific amount of time in which to complete its processing. The standard technique of insuring global optimization by employing multiple starting points was ignored here because of Chapter VIII results.

The "piggyback" approach of building on a previous best result was helpful, especially for small cost constraints. The approach reduced the area of search and led to somewhat better convergence. The results of these runs are presented and analyzed in the next section.

Optimization Results and Analysis

This section has two emphases. First, the numerical results of the Complex routine are examined for consistency with real world expectations. And the ability of these results to answer the several analytic questions posed in Chapter I and the introduction to this chapter is discussed.

As described in the previous section, two or three runs were made at each constraint level. The two "best" points in the factor space were identified at each constraint as those with the lowest PERTOT value. To help prevent adverse effects of random noise on results, the "best" points were chosen from the second half of the algorithm's iterations. That is, stray low values of PERTOT early in the optimization process were ignored. In particular, for the constraint 400 million won, the second iteration produced the second-best PERTOT level. But the $\underline{X}$ and $\underline{P}$ parameters for this point were far from convergence values, and the results could not be repeated. The conclusion was drawn that this point was a fluke, a result of random error. In future studies, a higher MONRUN would be prudent.

The average of the "best" points is presented, parameter by parameter, in Table 9.3. An average value is used because the flat surface encountered lends itself to area, rather than pinpoint, optimization. $\underline{X}$ and $\underline{P}$ parameters are easily identified in Table 9.3. Average performance values PERTOT, TDETH and TNUTD are given, along with average percent standard deviation figures. System cost COSTGX is uniquely determined by $\underline{X}$ and so is not a random variable. Four algorithm usage variables are presented as indicators of the ease of convergence for each constraint level. The number of iterations refers to the number of times a new superior point was found in the complex; the number of model runs indicates the number of times the algorithm requested a point value from the model, multiplied by MONRUN runs to give the actual number of one year simulation cycles. And CPU time refers to

Table 9.3 Optimization Results

	Budget Level					
	155	200	300	400	Uncon-Strained	
SDND	.00163	.00131	.00131	.000685	.000679	X
SDRC	.155	.160	.0913	.0997	.0660	
SDRS	.173	.168	.118	.149	.0661	
SAMPT	.0681	.0506	.0686	.0520	.0283	
SMPRC	.0684	.0541	.0465	.0346	.0280	
SMPRS	.0735	.0346	.0209	.0267	.0210	
DELD	.0358	.0177	.0123	.0144	.0106	
CG29	.913	.520	.0001	.225	.0198	
CG27	4.57	7.17	8.39	8.70	7.91	P
CG24	1.41	1.85	.615	1.33	1.38	
CG32	6.58	4.12	2.45	2.97	4.08	
CG30	17.9	22.9	21.5	21.2	18.8	
CG25	4.37	3.83	4.55	3.05	3.24	
PERTOT	.0920 (.0165) (.18)	.0699 (.013) (.19)	.0627 (.0135) (.22)	.0647 (.013) (.20)	.0601 (.012) (.20)	OBJECTIVES
Total deaths (million)	3.32 (.61) (.18)	2.547 (.48) (.19)	2.355 (.56) (.24)	2.367 (.60) (.25)	2.192 (.529) (.24)	
Total nutritional debt (1000 MT)	76.97 (34.9) (.45)	95.86 (22.0) (.23)	80.89 (27.0) (.33)	86.68 (36.0) (.42)	86.9 (27.7) (.32)	
Cost GX (million won)	149.1	182.9	276.5	280.6	654.2	
No. of Iterations	25	39	36	34	35	RUN PARAMS
No. of Model Runs	321	336	180	237	196	
CPU Time (sec)	1701	1702	904	1184	1002	
Convergence	No	No	YES	YES	YES	

computation on a CDC 6500. Convergence was based on meeting the β and α requirements within a given time-cost limit.

Model Validity

Let us first examine the aspects of Table 9.3 that confirm or cast doubts on the model's validity. Some conclusions are apparent from a first glance at the table. The final cost, COSTGX, stays significantly below its boundary, especially for the 400 million won case. This is a technical success, but the magnitude of the difference between boundary and result is disconcerting. There may be a way to improve convergence by allowing a closer approach to boundaries. Parameter δ should be studied in any future use of Complex; this parameter stipulates how far inside the boundary an offending factor value will be moved.

Several trends across budget levels are easily detected and follow expected patterns. A larger budget leads to better information quality as indicated by decreased optimal $\underline{X}$ values. This in turn leads to decreased death (TDETH) and PERTOT values; better information implies a better system, implying fewer deaths. Model computer time requirements also decrease with increased budget, reflecting the easier convergence path of reduced introduced error. Conversely, the likelihood of convergence increases with budget.

Other reflections on the computer model from Table 9.3 require a bit more study. The idea of quicker convergence with higher budget recieves support when examining the ratio of model cycles to the number of Complex iterations. For the five budget levels studied, the cycle-to-iterations ratios are 12.8, 8.6, 5.0, 7,0 and 5.6, respectively, for the budget figures in increasing order. The trend indicates an increased instance of a predicted better point failing, probably because variance of estimates increases with smaller budgets. To combat loss of reliability, an increase in MONRUN should help. Other algorithms may also prove more successful in dealing with higher levels of introduced error.

The budget level of 300 million Won is seen to be somewhat out of step with the other results. The objective values are very close to those of 400 million Won, but several of the $\underline{X}$ parameters are inconsistent, particularly DELD, CG29, SAMPT, and SMPRS. This appears to be a problem of the fuzzy, flat surface. In a larger scale project, it would be well to increase the number of model cycles (MONRUN) considerably.

Recall that an inverse relationship is expected between the two performance criteria TDETH and TNUTD. Figure 9.1 pictures TDETH versus TNUTD at the five budget levels of Table 9.3. Note that there is a slight but definite inverse relationship between the two variables. The 300 million, 400 million and unconstrained cases are clearly "Pareto-better" than the 200 million constraint. The 155 million Won case has a lower nutritional debt but "costs" one million additional lives.

Figure 9.1 also provides a vote of confidence for the use of minimum PERTOT as the optimization objective value. From earlier model runs it is known that the use of minimizing TDETH as the objective would make the TDETH-TNUTD inverse relationship much more pronounced. PERTOT makes clear the model's ability to improve performance with a larger budget (synonomous with better information, from Table 9.3).

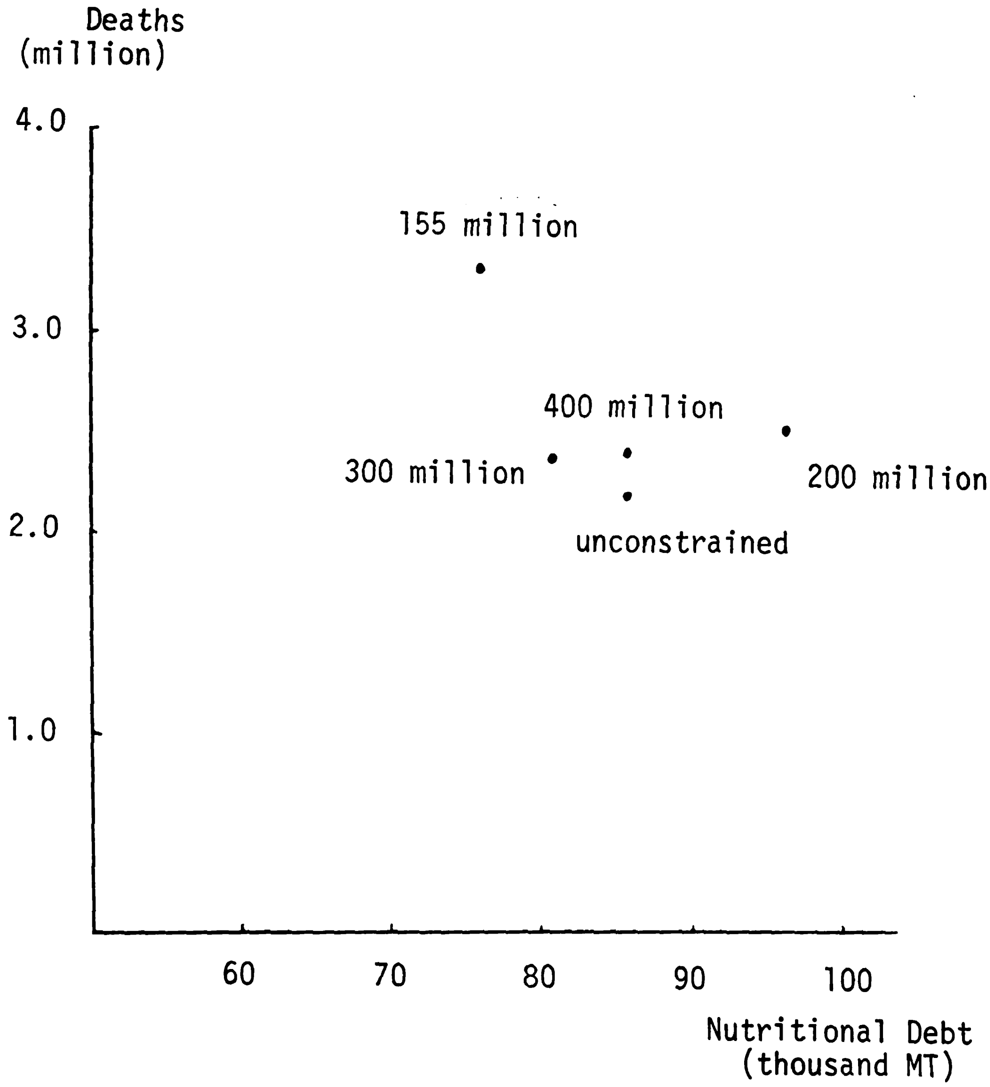


Figure 9.1. Nutritional Debt Versus Deaths at Varying Budget Levels

That is, the higher budget levels of Figure 9.1 are bunched in a position that is close to a Pareto improvement over the lower budget levels; PERTOT reduces deaths while keeping nutritional debt at acceptable levels.

One quirk is evident in Figure 9.1. Note that the increased budget from 300 million to 400 million won results in a worsened performance. This may be attributable to the fuzzy flat response surface. The fact that after a point, increased expenditure does not improve performance will be examined later.

Note the cyclical nature of solution to this overall problem. The results of the optimization are used as an additional check on the model's validity.

The Complex Algorithm

Table 9.3 also provides information about the worth of the Complex algorithm. A convergence pattern for the algorithm can be easily visualized by graphing performance versus iteration number in the Complex process. Two such graphs are presented in Figures 9.2, for the boundary budget cases. Four curves are actually given, two each for budget constraints 155 million won (A+B) and the unconstrained case (C+D). Curves A and C contain data from the first algorithm trial with MONRUN equal one, while B and D represent the final optimization.

Note that "stray" points on the curves are more prevalent in the early stages of the algorithm and for the MONRUN-equal-one trial. Such results are expected, as is the fact that the unconstrained curves are clearly below the constrained case. By continuing the comparison of constrained versus unconstrained, one sees that curve

D has a much narrower band of final values than does curve B, confirming the convergence of D and not B as stated in Table 9.3. The conparative ease of convergence for curve D is also indicated in the figures. Note that with less error, curve D had more algorithm iterations in less time than did curve B.

Based on graphical indications, the conclusion is reached that the Complex algorithm does converge to a satisfactory area of the factor space. Clearly, the degree of convergence is better for the more relaxed constraint cases, but the PERTOT performance achieved are near minimal at each budget level. The flat fuzzy surface and the nature of Complex values are used in Table 9.3. A more comprehensive study might present a range of parameter levels as indicated by multiple algorithm runs and would provide expected range estimates.

Figures 9.2 examine the convergence pattern of the objective value PERTOT. Another useful exercise would be to similarly study the behavior of $\underline{X}$ and $\underline{P}$ parameters as the algorithm proceeds. Convergence graphs, combined with the range-of-values study suggested above, would provide a clear picture of the confidence one can place in Table 9.3 values. A further study of the algorithm's effectiveness would be to examine the M-1 dimensional volume represented by the M points of the Complex. This volume should decrease with convergence, and a simple volume-versus-iteration graph similar to Figure 9.2 would be useful.

In light of the earlier discussion on the relative ease of convergence, it is interesting to study the actual and percent standard deviation figures for the three objective values, as presented in Table 9.3. Particularly for PERTOT, actual standard deviation

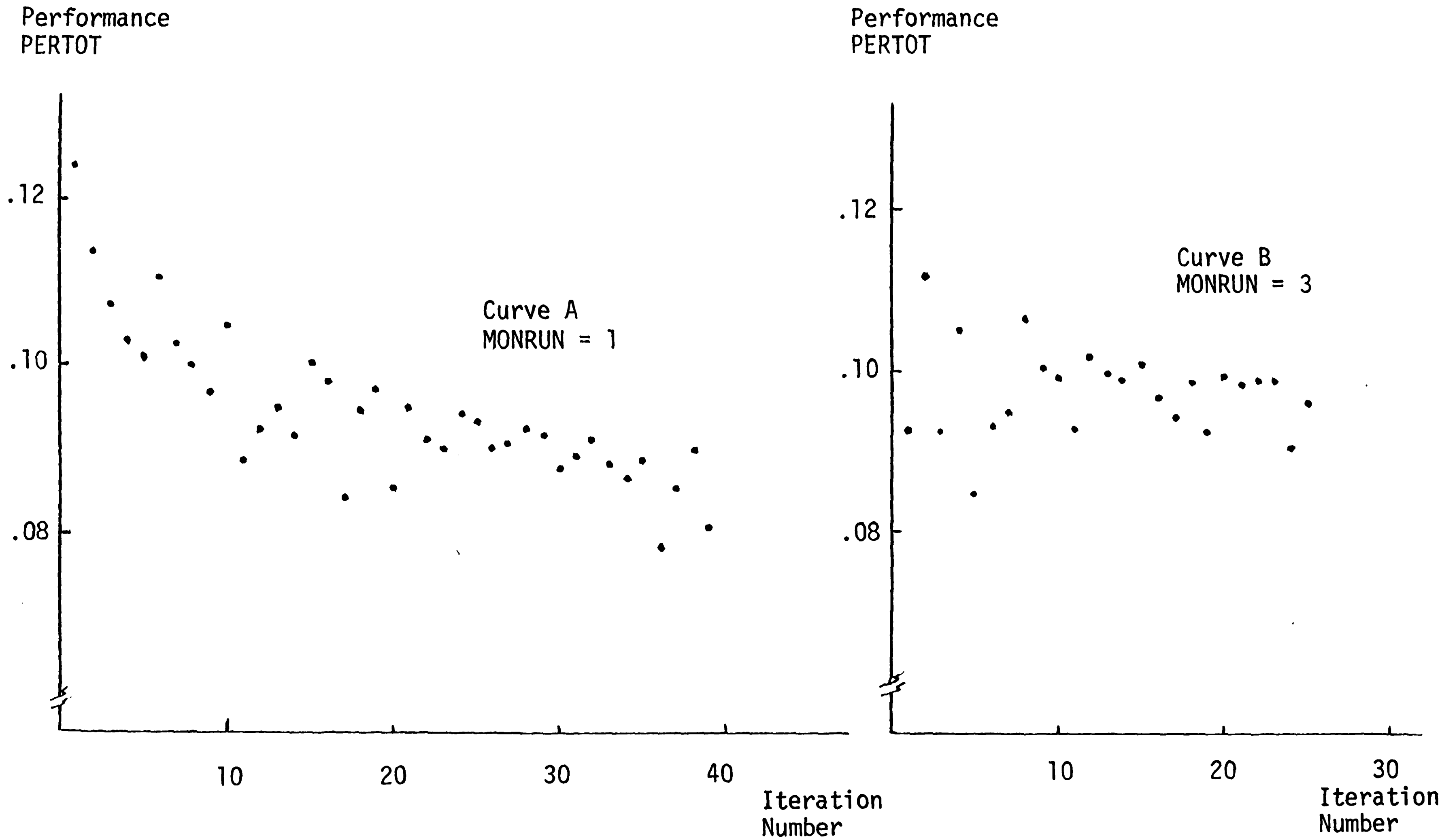


Figure 9.2a. Model Performance Variable Output at Each Algorithm Iteration -- Budget Level 155 Million Won

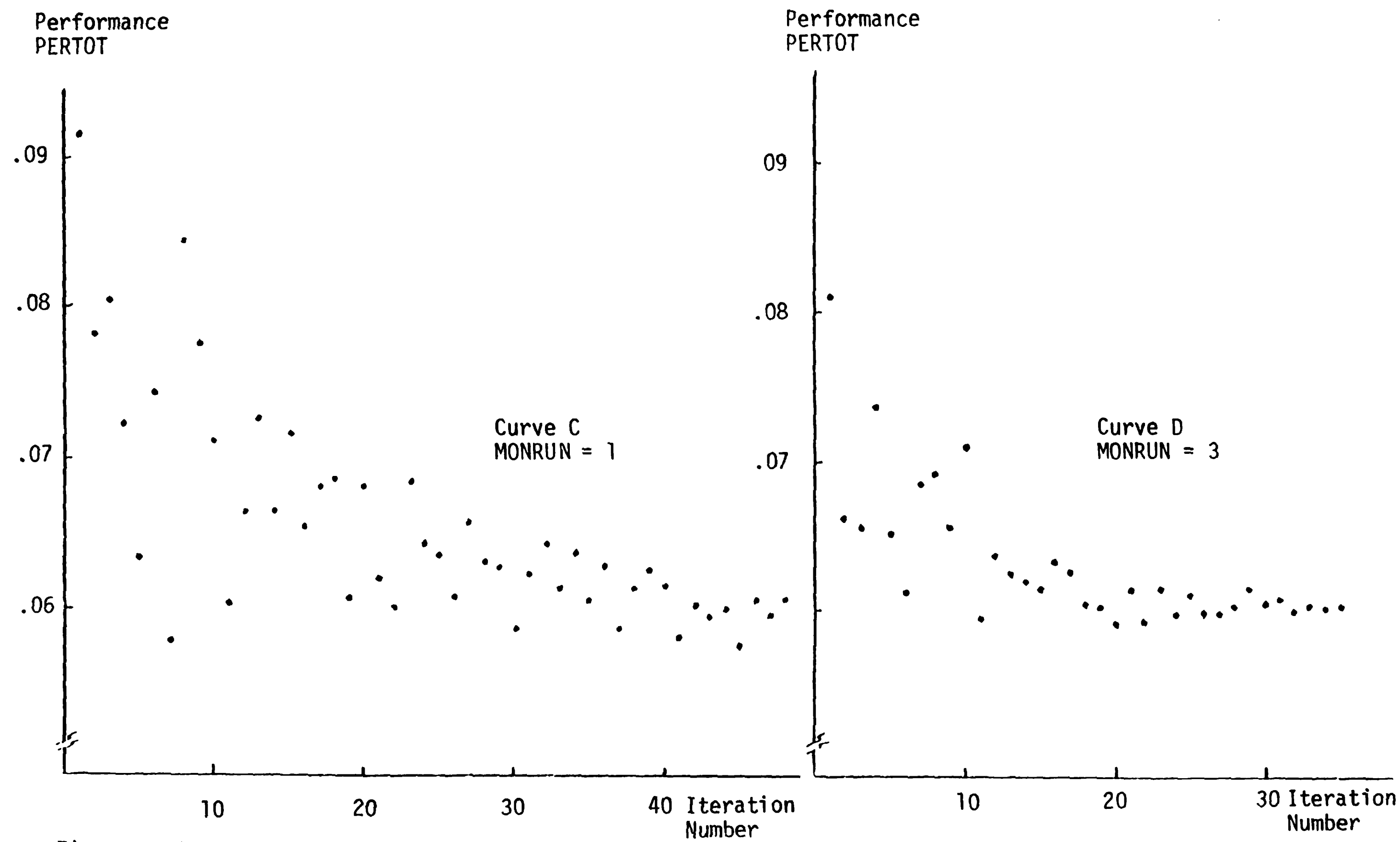


Figure 9.2b. Model Performance Variable Output at Each Algorithm Iteration -- Budget Level Unconstrained

increases with decreased budget; a larger input error leads to more variance in outputs. No clear trend is apparent for the percentage figures, although the PERTOT and TDETH values increase slightly with budget. It appears that within the range of values employed in the current experiments, model performance is consistent and not seriously distorted by increased input error. One further test would solidify this conclusion. Model calculated outputs, such as population, prices and production should be examined at the computed optimal points, to insure that the "best" values are not the result of some modeling quirk with no real world analog.

Comparison of performance figures in Tables 8.9 and 9.3 lead to the preliminary result that Chapter VIII optimizations were "better" than those in Chapter IX. But a closer look at the experimental guidelines show that the Chapter VIII figures are actually limiting cases of the Chapter IX studies. The purpose in Chapter VIII was to select a set of policy parameters for further optimization work. Accordingly, the information quality $\underline{X}$ was stationed at three different levels. The Table 8.9 "good" $\underline{X}_2$ corresponds to the limiting Table 9.3 "unconstrained" case, while the "poor" $\underline{X}_3$ roughly corresponds to the 200 to 300 won case (See Table 8.3). Thus the seemingly better performance in Chapter VIII should be expected.

A weakness in the chosen Complex method parameters shows itself in the comparison between the tables; the convergence criteria are too loose, allowing the algorithm to stop short of a possible optimal point. But besides this weakness, the two tables support the model's validity, because the objective values are close, the five policy parameters are close, and the run statistics are very similar.

A study of Table 9.3 has revealed no glaring model or algorithm inconsistencies. Only the ability of the algorithm to combat model randomness is suspect. Let us now move on to an examination of the factor space, the information quality and policy parameters.

Translation to Information Quality Terms

The optimal $\underline{X}$ values of Table 9.3 can be translated to more familiar terms. Recall that one of the prime considerations of Chapter V was that the cost function had to be computed in such a manner that once an optimal $\underline{X}^o$ point was found, a unique information system would be identified. By using the component descriptions in Chapter V and the calculations outlined in Appendix A, the optimal system at each budget level can be defined in terms of three information system types. First, the data transmission delay, in days. This is available from the delay parameter DELD. Second, the sampling interval, in days. Each sampled variable has its own interval, represented by $\underline{X}$ parameters SAMPT, SMPRC and SMPRS. Finally, standard deviation parameters SDND, SDRC and SDRS can be translated to provide the sample size, the number of persons or households.

The delay and sampling interval are computed easily by converting years to days. The sample size can be computed using the formulas derived in Appendix A, repeated here as Equations 9.4. The statistical method explained in Chapter V (see Equation 5.22) also provides a survey cost, based on allowable error and frequency. The aggregate cost formulae are also repeated from Appendix A as Equations 9.5. The six equations indicate the relationship between error and sample size and among error, sample frequency and cost.

$$N_{nutrition} = .0059 / SDND^2 \quad (9.4a)$$

$$N_{consumption} = 10.6 / SDRC^2 \quad (9.4b)$$

$$N_{storage} = 9.2 / SDRS^2 \quad (9.4c)$$

$$CSUR_{nutrition} = 875{,}000 + (5000 + 1.297 / SDND^2) / SAMPT \quad (9.5a)$$

$$CSUR_{consumption} = 1{,}312{,}500 + (5000 + 14058 / SDRC^2) / SMPRC \quad (9.5b)$$

$$CSUR_{storage} = 875{,}000 + (5000 + 7086 / SDRS^2) / SMPRS \quad (9.5c)$$

where:

N = sample size (persons for nutrition, households otherwise)

CSUR = survey costs for one year (won)

SDND,SDRC,SDRS = allowable error parameters

SAMPT,SMPRC,SMPRS - sample frequency parameters.

Table 9.4 presents the translated information quality parameters, sorted by system component. The cost for each optimal component at each budget level is given, along with the component cost as a percentage of the overall system. Transmission delays and sampling intervals, as well as sample size, are noted. In addition, the type of transmission system as described in Chapter V (see Figure 5.1) is given.

Before examining the feasibility of the items of Table 9.4, let us take a look at the overall picture. Each column gives best information system parameters to be followed at that column's budget level. For example, the most inexpensive system in the table calls for QUAC stick measurement of 2221 children and consumption surveys of 441 households every twenty-four days. Personal storage supplies would

Table 9.4 Information Quality
Parameters Translated to Sampling Terminology

CATEGORY	Data (Units)	155	200	300	400	Unconst
		BUDGET CONSTRAINT LEVEL (Million Won)				
Transmission Delay	DELD (Days)	12.7	6.3	4.4	5.1	3.8
	Won (Million)	126.9	145.0	180.3	159.3	233.3
	%	85	80	70	59	44
	Type	Two-Way Transceivers	Minicomp	Renovation	Renovation	Renovation
Nutritional Sampling	SDND	.00163	.00131	.000131	.000685	.000679
	SAMPT (Days)	24.2	18.0	24.4	18.5	10.1
	Won (Million)	8.1	15.9	12.0	54.1	100.5
	%	5	9	5	20	19
	n (Persons)	2221	3438	3438	12574	12797
Consumption Sampling	SDRC	.155	.160	.091	.100	.066
	SMPRC (Days)	24.4	19.3	16.6	12.3	10.0
	Won (Million)	9.9	11.6	37.7	42.3	116.8
	%	7	6	15	26	22
	n (Households)	441	414	1272	1066	2433
Storage Sampling	SDRS	.173	.168	.118	.149	.066
	SMPRS (Days)	26.2	12.3	7.4	9.6	7.5
	Won (Million)	4.2	8.3	25.5	13.0	78.3
	%	3	5	10	5	15
	n (Households)	307	326	661	414	2106
Total Won	From Appendix Equations	149.1	180.8	255.5	268.7	528.9
Total Won	Model Results - Table 9.3	149.1	182.9	276.5	280.6	654.2

be sampled for 307 households every twenty-four days. The result of each survey would reach decision makers some twelve days later. The cost for this service for one year would be approximately 150 million won. With the given policies and systems for distribution and allocation, the projected death total is 3.32 million and the overall nutritional deficit is 77,000 metric tons of grain at the end of the year.

Similar descriptions can easily be generated from Tables 9.3 and 9.4 for each budget level. These descriptions are one of the prime results of the current work. This is no mean accomplishment.

Let us now examine the details of Table 9.4. Two different total cost figures are reported in the table. The first is a sum of the component costs calculated from Equations 9.5 and Figure 5.1. The second is the COSTGX figure reported in Table 9.3. The reason that the two totals differ is that all values reported in Table 9.3 are the averages of two model simulation runs; comparison of single model runs would tie exactly. It is interesting that the totals diverge with increased budget. Based on convergence criteria, the averages would be expected to coincide more closely with the more relaxed constraints. But the opposite happens here.

Two reasons can be cited for the apparent discrepancy, both indicating that convergence of PERTOT is not the most important factor in determining system cost. The first reason derives from Equation 9.5. Cost increases as the squared standard deviation decreases. That is, cost becomes more sensitive to a change in allowable error as that error drops. Any difference in the standard deviation between the two "best" simulation runs is magnified at higher budget levels.

Second, the close match of cost calculations at the low budget levels is caused by high fixed costs. Recall that the minimum system expenditure is 140 million won. The lower budget levels effectively restrict the X factor space. Since cost is a non-stochastic function of X, it is restricted also. But the range of X includes large error parameters so that the objective value PERTOT does not converge.

To combat the divergence of the two total cost figures, the convergence criteria must be tightened for higher budget levels. This would force the average X vector closer to actual simulation results.

Policy Results

Let us now examine the individual X and P variables as reported in Tables 9.3 and 9.4. The five policy parameters appear only in the first table, as they do not directly affect the information system design. Of the five parameters, three show possible meaningful trends.

The parameter for nutritional debt control in the emergency feeding equation (Equation 2.15) is CG27, which increases with the budget level. That is, control is tightened with better information, causing quicker response in moving food from rurals to urbans. On the other hand, nutritional debt control CG32 in the sales equation (Equation 2.14) decreases with budget. Control is relaxed here with better data, meaning that the rich are not as burdened. The effect of the CG32 trend is an advantage of good information; better data allows decision makers to tax the rich less heavily. That is, the equalization policy may be hard to implement, but better information makes it easier.

A second instance of the model showing the advantages of good information is found in the performance of CG25, the crisis transport increase parameter (Equation 4.5). CG25 decreases slightly at higher budget levels, implying that the better data allow the normal operating system to work more efficiently. There is less of a dramatic increase at the crunch. Both CG25 and CG32 respond consistently with Chapter VIII performance (see Table 8.9).

The two remaining P variables are fairly consistent across the budget levels. CG24 and CG30, the consumption control on emergency food distribution (Equation 3.8) and the rural private storage control on the acquisitions equation (Equation 2.13), respectively, give indications that they do not belong in the final optimization. Recall that both parameters were included in the final tests because they varied widely in earlier runs (Table 8.9).

If only CG25, CG27 and CG30 were to be factors in an optimization, the consumption and rural storage influence on policy would be fixed. This raises the question of how well the system would perform if these policy variables were excluded entirely. A modification of the model eliminating consumption and storage sampling and their respective influence on allocation decisions would allow such a check. This suggests a user-oriented enhancement of the model, providing a choice of combinations of sampled variables and control equations to be performance tested. This would be in addition to the current capability of changing and optimizing on control equation paramters.

Tracker Results

The α-β tracker variable CG29 (Equation 6.6) is the only X parameter that does not lend itself to a common usage translation, although it is tied to the X consumption parameters. It is clear that

CG29 decreases with increased spending, paralleling the decrease in consumption sample interval (SMPRC) and standard deviation (SDRC). The rule being stated here is that with more frequent sampling and increased accuracy, a smaller β value should be used. How does this rule relate to the tracker? Recall the tracker design discussion of Chapter VI. The choice of β is based on desired response characteristics. β close to one is desirable for quick response to new data, and β close to zero helps to suppress error.

The optimization results show that less frequent sampling with more error has β close to one, while more frequent, less noisy sampling has β close to zero. As is often the case, sample frequency and allowable error are at odds here. Evidently CG29 is affected more by interval than accuracy. If error were the only question, then the β should be closer to zero for low budget. But the opposite is true. The determining factor is that as the sampling interval increases, β approaches one so as to weigh more heavily the new (and infrequent) data.

Information System Results

Several interesting concepts result from a study of the $\underline{X}$ information quality parameters of Table 9.4. The sampling intervals are nearly the same for nutritional and consumption surveys, especially at the boundary budget cases. This suggests that some efficiencies could be achieved by having teams sample both variables at the same time, subject to statistical constraints and the affordability of multitalented personnel.

The sampling interval for storage is generally less than for the other two variables. There are two possible explanations for such a relationship. First, it may be that storage needs closer monitoring to provide data that affects performance. The other option is that the storage sampling cost does not prohibit more frequent samplings as the consumption or nutritional measurement costs do. The second explanation is the more feasible, based on the percentage cost figures of Table 9.4. Note that the cost of storage surveillance is the smallest portion of the overall system at four of the five budget levels.

It is good to examine the sample size figures of Table 9.4 to determine if they fit the real world situation. The crucial aspects of sample size are that the number fits the actual population and that the planned number of teams can reasonably be expected to perform their tasks in a short amount of time. Increased staff would alter the cost function while increased measurement time would invalidate transmission times and possibly the statistical optimization routine.

Let us examine the feasibility of the sample surveys defined at the highest budget levels of Table 9.4. The nutrition surveys call for examination of 12797 persons, or about .04 percent of the total initial population. This is reasonable, but recall that the chosen QUAC stick method can only be used on children. Also, the model assumes that a survey of the whole country is needed, whereas a true famine would concentrate by region. The number of samples is high, but the QUAC stick method may accomplish the task. Given that a team of two observers can sample two hundred children per hour (36), the 12797 measurements can be obtained in sixty-four team-hours, or about three hours for each of the twenty-four projected teams.

However, the two hundred per hour figure does not include the time consuming tasks of sample selection and travel. Too much time spent will affect the assumption on delay costs, while too much travel jeopardizes the sample size function of Chapter V.

Consumption and storage surveys do not appear to be as feasible as the nutritional, mainly because the time allotment per survey is much higher. Given one-half hour per household (42), the 2433 consumption samples would necessitate twenty-six hours for each of forty-eight individuals. The fact that the time between surveys is only ten days implies that almost continuous sampling would be necessary. Similarly, the storage measurement of 2106 households would require eleven hours per observer, given a sampling rate of four per hour. Note that these sampling rates do not include travel time, so that the survey interval of 7.5 days would be quickly reached for storage sampling also.

There are at least three possible cures for these lengthy survey times. The real-world situation can be aided if unit sample times are reduced, as has been suggested elsehwere (64). Two model particulars should be carefully examined. The population standard error parameters S_h for Equation 5.23 may not be estimated correctly. And the equations themselves may not be valid, especially since travel time becomes a very large consideration. Also, delay as a function of measurement may have to be added to the cost function formulation (see Chapter V). The most reasonable selection, from a real-world perspective, may be to drop consumption and storage as measured variables. The usefulness of a computer model cannot be overemphasized at this point. A set of model runs at varying levels of S_h can indicate answers to the tough questions of estimating a proper size for the population variance.

Information System Priorities

The X variables do behave in an expected fashion. The higher budgets lead to better (lower) X values and better system performance. A question remains. Given a budget cut, which X variables are the most crucial? Or, with limited resources, which parts of the information system should have priority?

One figure that provides a comparison is the percentage of total expenditure from Table 9.4. Note that the transmission cost is consistently the largest expenditure of the four components. But the percentage cost is affected by the fixed costs and does not account for the difference in component units. That is, component costs are related to X variables which have varied allowable values and varied cost structures.

To combat the problem of non-comparable variance, one could compare the X values as percentages of their respective allowable ranges, as stated in Table 9.1. But fixed costs are still not accounted for, and the ranges of Table 9.1 are subjective.

How then do we compare X variable worth? Two concepts are important. The first is that of a percentage change in the cost of the component. The percent change smooths out the effects of fixed costs. The second concept is that the change in cost (or variable value) must be tied to a change in system performance. Recall that the use of sensitivity tests, as conducted in Chapter VIII, is one method for measuring the change in performance due to an input variable change. But a less time-consuming method presents itself here.

Another way of wording the current question is which extra investment in information system components will have the greatest positive results? To put this into a numerical setting, let us examine performance variables versus cost. Figure 9.3 presents performance values PERTOT and TDETH as functions of cost COSTGX. The values are taken from Table 9.3 and represent all five budget levels.

Note first that the shapes of the two curves are very similar. This is another confirmation that PERTOT is an acceptable optimization proxy for TDETH. A second, and more important, consideration is that curves show marked performance improvement for low budget levels but then reach a plateau where extra expenditures contribute only minimal system improvements. Marginal performance increases are negligible for investment greater than three hundred million won. At that point system improvements must come from other sources: more food, better policies, or more efficient transportation and distribution operations. This plateau is reflected in Figure 9.1 where the three hundred million, four hundred million, and unconstrained budget levels produce similar results that are a marked improvement over the 155 million won case.

The implications for studying the X variables of Table 9.3 and 9.4 are clear. The changes in X value and resulting expenditures between 155 million and three hundred million won are likely to be more productive than the changes from three hundred million won to the unconstrained budget level. A means of measuring and comparing the stated changes is needed. The measurement must account for fixed costs, differences in variable units, and effects on performance.

Equation 9.6 defines a measure which meets the required criteria. The function H is a ratio with the change in performance between the minimal budget case and higher cost levels as numerator and a

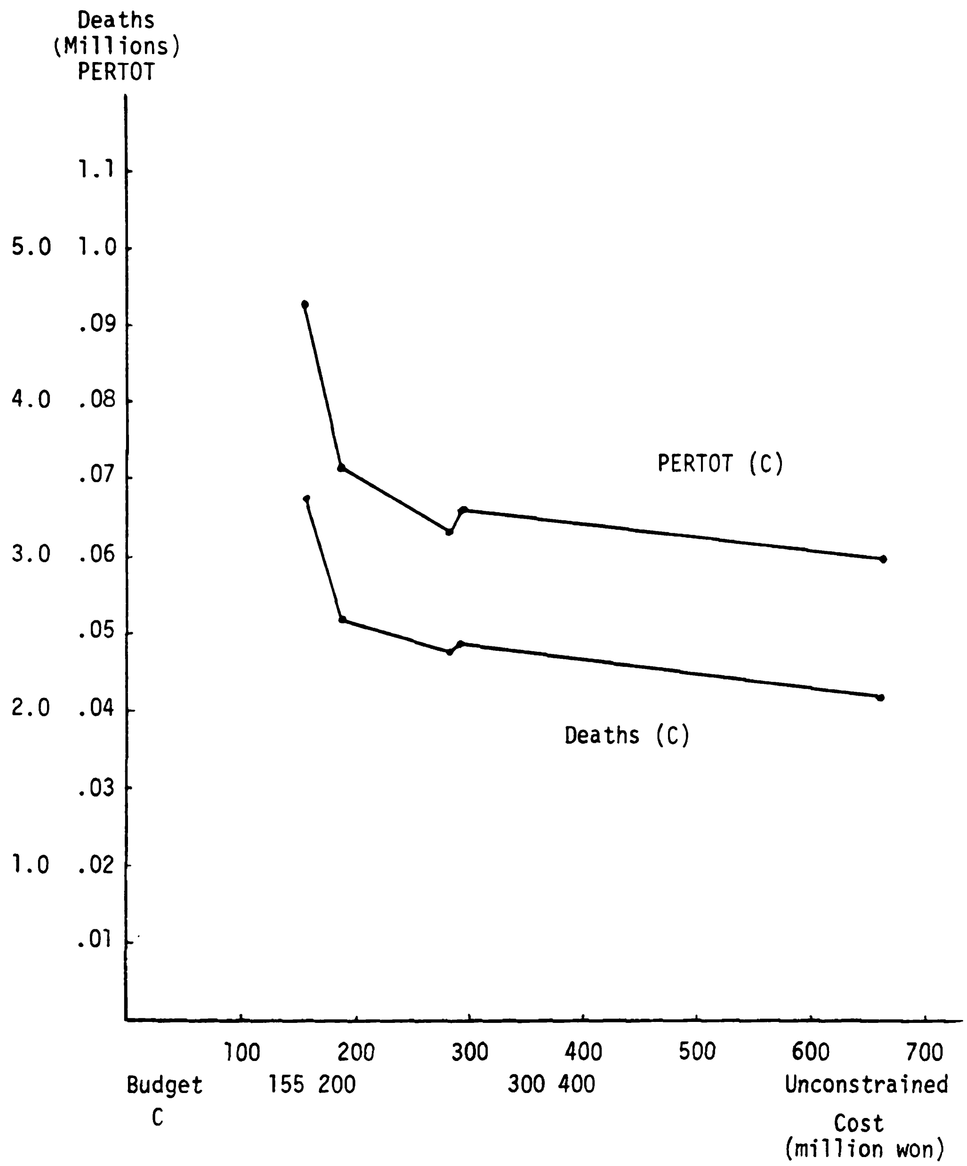


Figure 9.3. Performance Versus Cost

denominator comprised of the range of the X variable. The ratio of differences allows a comparison across X variables.

$$H_i(C) = \frac{X_i\ (155) - X_i\ (C)}{R_i} \qquad (9.6)$$

where:

H = comparative performance measure on information quality parameters (dimensionless)

C = budget level (won)

X(C) = optimum information quality parameter at given budget level

R = defined boundary on range of X_i (from Table 9.1)

i = index on quality parameters.

The numerator of H serves to smooth the fixed costs problem and compare performance differences. Note that costs are a direct function of X so that studying X changes is the same as studying cost differences. The ratio of X_i differences eliminates the variable unit and cost structure problems with one proviso. The range definitions of Table 9.1 must be equitable. That is, each range must reflect a standard likelihood that the optimum X_i falls within the range. Recall from Chapter VIII that the ranges of Table 9.1 were subjectively selected after a multitude of model sensitivity tests. A more precise range calculation method would increase the validity of measure H.

Figure 9.4 presents H values for X variables at each budget level. Calculations were performed using Equation 9.6 and Tables 9.1 and 9.3. A large $H_i(C)$ value in Figure 9.4 indicates a large change in X_i between budget level C and the 155 million won level. The difference $H_i(C_1) - H_i(C_2)$ shows the magnitude of change in X_i between budgets

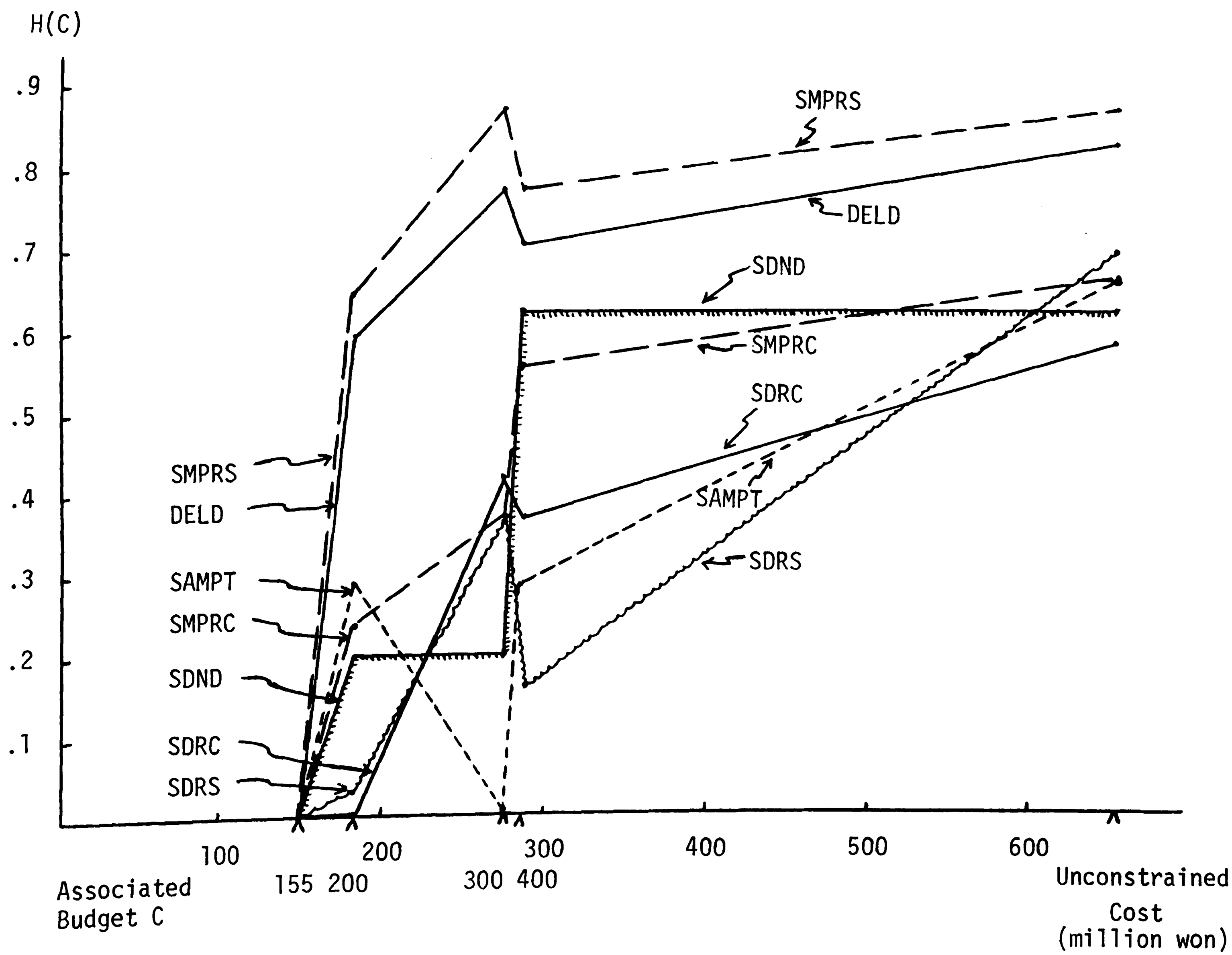


Figure 9.4. Performance Versus Cost Measure H(C)

C_1 and C_2. The discussion of Figure 9.3 implied that a desirable pattern would be to have $H_i(200)$ and $H_i(300)$ large. A secondary consideration would be that the differences $H_i(400)$ - $H_i(300)$ and $H_i(500)$ - $H_i(300)$ be small.

The most striking feature of Figure 9.4 is that the delay parameter DELD and the storage sampling frequency SMPRS are dramatically "better" than the other five X variables. Both DELD and SMPRS have large H at low cost.

At the two hundred million won budget level, three second-priority parameters are identifiable: SAMPT, SMPRC and SDND. And the remaining two variables, SDRC and SDRS, show minimal change at the two hundred level. But both SDRC and SDRS rebound to have high H at three hundred million won, while SAMPT declines sharply. Such large fluctuations may indicate that these variables are not reliable predictors of system performance.

Based on the previous observations, there appear to be three priority levels among the individual information quality parameters. First, DELD and SMPRS are superior. Expenditure for reduction of transmission delay and increased storage sampling should be of primary concern. Additional expenditures would go toward increased consumption sampling and reduction of nutritional measurement error since SMPRC and SDND show steady improvement in Figure 9.4. Finally, SAMPT, SDRC, and SDRS should be supported only at a level necessary to keep the information system in balance.

Let us now examine Figure 9.4 with reference to groupings by type of parameters. It is clear that the delay variable is superior to either frequency or error parameters. And, at the two hundred million level, frequency parameters score consistently higher than their error counterparts. The situation is clouded at the three hundred million level since oscillations make the superiority of frequency over error less evident. But based on this one graph's evidence, it is possible to rank information quality by component type: delay, frequency, error.

Note that it is somewhat inaccurate to make these priority statements, since the optimum points shown in Table 9.3 are combined effects of all $\underline{X}$ variables. The measure H provides an indicator, not a definitive statement. Also, the generality of these rankings cannot be discerned here. It would be necessary to examine many model variations before making general statements. Real-world experience must provide the final test.

Conclusions and Summary

The model seems to perform well based on the reliability and expectedness of outputs. The issues of model variance; algorithm convergence; the use of a single variable performance function; and the cost-change trends of information quality ($\underline{X}$), policy parameters ($\underline{P}$) and system performance have all been faced.

More importantly, the approach provides quantitative answers to the several questions posed in Chapter I and the introduction to this chapter. Optimum information system alternatives at several budget levels are derived and presented in Tables 9.3 and 9.4. The expected performance level is also given in Table 9.3 and is pictured in Figures 9.1 and 9.3. A standard deviation is given in Table 9.3 for each variable and performance, so that ranges of likely values can be computed.

Table 9.4 provides suggested monitoring statistics for the real-world variables included in the model. As mentioned previously, a fuller explanation of the problem would greatly expand the decision-making portion of the model to include such variables as water and medical supplies, incidence of illness, and transport availability.

The results of the approach touch not only on information quality, but on operating levels for policies. The $\underline{P}$ portion of Table 9.3 ties operations to information quality.

The relative importance of $\underline{X}$ components is examined. The cost breakdown in Table 9.4 allows a comparison of absolute expenses across information quality components. And the measure H of Equation 9.6, along with its related graph in Figure 9.4, lead to a prioritized spending list for information: timeliness, frequency, accuracy.

It should be noted here that in this complex system, the numerical results of this chapter depend a great deal on the situation set in previous chapters: the cost function, the raw data, the model assumptions. The model validation work of Chapter VII must be done prior to optimization, but its real worth is not evident until the optimization results are scrutinized.

Once again, many valid research projects have only been touched in passing. A great amount of wisdom is needed to anticipate the most crucial areas for work, since extended research is not possible in a famine or in famine-related work. The following items are mentioned as means of improving on the present optimization framework.

The single performance criterion of Equation 9.2 allows for different weighting patterns. A study of several disparate weightings would be useful in relating the numerical optimization package to the real-world results of lives saved, nutritional debt, and available grain.

A deeper look at the results of a price control policy should be made, as well as exploration of other policy alternatives. It is likely that the criteria of Equation 9.2 will need to be significantly altered to fit a different policy structure.

Further convergence tests on Complex and its boundary parameter would help to delineate the causes of output fuzziness. Error parameters, the optimization algorithm and the model itself contribute to the flat, fuzzy surface encountered. It would be very useful to make more precise statements about the causes of output variability.

The effects of cost function changes on optimization results should be studied. Such an examination would provide great insights into the relative worth of $\underline{X}$ parameters and information system components.

PART III

CONCLUSIONS

CHAPTER X

RESULTS AND SUMMARY

A systems approach to nutrition in general and famine relief in particular is a large project. This dissertation has not been an exception. The goal of this chapter is to attempt to tie the package together. The major results of the study are presented first. Following sections are devoted to general observations about concepts likely to be encountered during application of the approach, advantages and disadvantages of the method, and a presentation of areas for further related research.

Major Results

The simulation approach outlined in Figure 1.2 and described in this dissertation is a viable option for the study of information systems. Computer simulations are excellent tools for the study of complex, quantifiable processes, and the sampling component developed here allows macro simulation of an information system. An example problem has been followed through the approach to a successful conclusion.

The computer simulation model has shown that it can be an invaluable asset. A model can definitely serve as a design tool. The model can be used as an educational tool for decision makers, an aid in discerning the relevant outputs to be aware of when plotting relief strategy. And a refined model could serve as an on-line predictor during an actual famine. In each application, the computer simulation would provide a deeper insight into the problems to be faced. Many questions about relief work are answered and many more relevant questions are unearthed as a result of simulation analysis.

Information quality has a great potential as a model validation tool. The assumption that better information should lead to better system performance leads to a thorough study of model and policy structure as well as model and policy parameters. Similarly, the sampling routine described in Chapter III is a useful general modeling tool. It can simulate many data quality sets as part of a large simulation or can be used to test the efficacy of filters and predictors.

It has been demonstrated that optimal policy implementation varies with information quality. This requires the current problem formulation to include a performance function dependent on both policy and information quality ($\underline{F}(\underline{X},\underline{P})$).

An alternative to multi-variate optimization was found to be both useful and accurate. The single variable PERTOT served as a proxy for the defined optimization variables of nutritional debt (TNUTD) and total deaths (TDETH). PERTOT was defined in Chapter VIII as a weighted measure of the percentage death figure in the four population classes (see Equations 8.7). Such a weight was picked to complement the stated policy of equalizing nutritional debt across the classes. In optimization runs, minimizing PERTOT led to a minimization of TDETH with TNUTD at acceptable levels. The key finding is that the policy and goals of the real world system can lead to a useful measurement and objective value in the model.

Three items emerge as important issues for relief efforts to address. Study of the simulation model in Chapter IV shows the crucial effect of consumption patterns on relief policy. An additional aspect of this problem is the long-term education implications of poor consumption habits. Secondly, there is a harsh question to be answered when outside aid is not enough to meet a food shortage. Will short term (two-three months) or long term (one year) solutions be implemented? The long term solution requires the unpopular imposition of immediate rationing, but has significantly better results when the crisis peaks. Finally, the ability to predict famine extent is important. In Chapter VIII, a twenty-five percent change in crisis level produced a change in model results approximately equal to shifting from the best to the worst information system. When the goal is minimization of deaths, poor estimation of this one variable can undo the finest design work.

A comparison of the relative importance of policy choice and optimization can be made, based on five model benchmarks. The original price control and equalization strategies of Chapter II, the modified policy without optimization of Chapter IV and the optimized results of Chapters VIII and IX provide the basis for comparison. Each output was generated at a mean crisis level of two million metric tons and optimal information quality. Table 10.1 contains the relevant data.

Note the continued inverse relationship between total deaths (TDETH) and total nutritional debt (TNUTD). Also note the tremendous

Table 10.1 Comparative Performance at Five Points in Study

Benchmark Description and Chapter of Occurrence	TDETH (million)	TNUTD (1000 MT)
Price Control Policy Chapter 2	10.5	0
Original Equalization Policy Chapter 2	5	50
Revised Equalization Policy Chapter 4	3.5	80
Manual Optimization Chapter 8	1.76	102
Complex Algorithm Optimization Chapter 9	2.19	87

improvement of equalization policy over price control. As mentioned in Chapter VIII, further model work should improve the price control results, probably reducing TDETH to nine million.

It appears that the complex algorithm does not lead to a substantial improvement in system performance. But the system description resulting from the manual optimization in Chapter VIII is poorly defined. The success of the manual optimization is due more to the flatness of the response surface than to the method itself.

On such a flat, fuzzy surface, no algorithm is likely to produce exact quantifiable results. But an algorithm such as Complex has the valuable feature of simultaneous variance of all input variables, allowing a study of interactions. And the results of Complex are well-defined according to performance.

As mentioned in Chapter IX, another reason for the seemingly worsened performance of the Complex method is the fact that information error is introduced. Each of the other four benchmarks was run at "Clairvoyant" information levels, with no random error or delay in information.

Improved policy reduces deaths by 1.5 million. Optimization led to an improvement of some 1.3 million. So policy modifications and optimization are similar in their ability to improve the modeled relief system. The choice of policy appears to be more important.

In any large scale project, the wisdom to know what to look for is vital. Several stages of this dissertation, particularly Chapters IV and VIII, demonstrate the overwhelming truth of this statement. Such wisdom is not guaranteed by expert help or hard work; it is a gift.

Observations on the Approach and the Current Problem

The numerical outcomes of this study are meant as indicators of the nature of expected results, not as actual recommendations, mainly because the model has not been adequately validated against real famine data. In fact, the model background is a hypothetical mixture of two countries. Thus, more important than numerical results is the type of outcomes encountered. Chapter IX produces the numerical data mentioned in Chapter I as aids to planners: optimal system descriptions at several budget levels, likely levels of performance for each alternative and priorities on system components, variables to be monitored and surveillance parameters. Study of the model alone results in a broader understanding of system processes, as described in Chapter IV and VII.

In following the current example through the methodology of Figure 1.2, several items became clear on the structure of the approach and its relation to the example. The cyclical nature of simulation work carries over to the approach itself. An example appears in Chapter IX. The use of sampling Equation 5.21 and the assigned value of parameter S_h within the equation may be invalid for consumption surveillance because of time and transportation constraints. This was discovered in the optimization phase and could result in a restructuring of the cost function. Note that this leads to an observation about the validation process. Validation should extend to the modeled function $G(\underline{X})$, insuring that modeled alternatives actually do provide the cited information quality.

Relief system performance is likely to be a fuzzy, flat surface. Thus, the goal of the optimization stage should not be to pinpoint parameters. Rather, the discovery of a cost value where a performance plateau begins would be most helpful (see Figure 9.3). Too high powered an algorithm will be wasteful in this context. The Complex algorithm is easily programmed and operated, and it converges satisfactorily. It is a good optimization alternative here. On the other hand, manual sensitivity tests are unreliable as an optimization tool because the results are very poorly defined. I would recommend that the final optimization stage of Figure 1.2 be avoided unless an algorithm package is available.

Based on tasks performed for this dissertation, the areas where most research and analysis effort can be expected are:

-- development of $G(\underline{X})$

-- construction and testing of the model

-- development of experimental scheme/design

The actual experimentation and interpretations go quickly once the above items are in place.

There exists a great tendency to want a more and more detailed model. But, detail leads to disaggregation (by class, region, variable type, time, etc.). This makes it harder to analyze outputs because of the volume of data, and the large number of parameters makes optimization more difficult.

At several points the concern has been voiced over the implementability of this systems approach. The usefulness of this or any other planning methodology depends more on the level of commitment of the government than on the worth of the methodology.

Advantages and Disadvantages of the Approach

Most importantly the current approach provides a frame work for future research on famine relief information systems. As seen in Figure 1.2, performance is tied to cost and to information quality variables. The final output is a set of criteria for information system design: optimal system descriptions, likely performance levels and priorities for resource allocation between sampling error, delay and frequency. The approach combines the tools of management information systems (MIS), computer simulation, optimization, and cost-benefit analysis.

Several segments pictured in Figure 1.2 can be used individually to provide rich rewards. The validation stage and construction of the simulation model are powerful learning tools, as discussed shortly. The cost analysis used in generating function $G(\underline{X})$ must sort through policy information needs while constructing alternative mechanisms for obtaining data. It must also evaluate restrictions on money, manpower, equipment and time; much useless evaluation can be eliminated by limiting the scope to feasible alternatives immediately.

A sampling component added to the simulation model allows study of results of given information quality without specifying the details of surveillance and processing. So criteria sets are evaluated which can cover a multitude of alternatives. And the sampling component allows evaluation of information filters even without the remaining simulation components.

A simulation is a powerful tool. Use of the computer allows comparison of a multitude of situations quickly, examining results of varying initial conditions, data collection parameters, data collection variables and MIS-policy combinations. Sensitivity analysis can help indicate further work priorities.

The numerical comparisons in simulation work are useful. Exploration of satisfactory answers to the repeated question "why?" is even more helpful, as related in Chapters III and IV. Knowledge of trends and cause and effect relationships as well as the recommended parameter and performance levels results from this excellent learning tool. Understanding component linkages and the relationship between policy structure (the equations) and implementation (the parameters) can help identify problems to be met in implementation.

The simulation can be useful in different forms to several governmental units. By removing the sampling component, one can examine results of varying crop failure levels. Optimal timing for imports and foreign aid distribution has already been studied (38). Identification of the important links to transport and distribution systems is possible, as well as management and training requirements. And policy making is enhanced as the model helps set criteria for information quality.

Finally, the feedback equations and cutoff levels used in the modeling of policy structure lead directly to MIS rules in the implementation stage. The learning process of studying the model can bear fruit when examining specific operating procedures for field programs and the transport system.

There are two main disadvantages to the current approach. It requires a high degree of systems sophistication which may make it difficult to implement in a third world setting. And some issues are outside the scope of the analysis portion of the approach.

A fairly high degree of computer technology and software power will be needed which may not be readily available. Possibly more limiting than the need for computer power is the need for a sophisticated level of data for the model. A real-world data base is not available for much of the performance and cost data that would allow comprehensive model validation.

The approach, in its full scope, is a time-consuming process in a field where time is a major constraint. In addition, the cost function $G(\underline{X})$ is defined in a form not normally developed, making it harder than usual to obtain. Uniform goals and objectives are central to a "systems" approach, but these are generally not available in the sectored government commonly found in the third world (17).

Although this approach is a framework for design, it does little to explain how to set up alternatives or implement a designed system. Expertise in these areas would be logical components of a systems team.

Topics for Further Research

The tremendous number of tasks to accomplish in any relief effort is staggering. Even with limiting the scope of the current study to the role of an information system, many complex components have been noted. The purpose of this section is to draw together some of the topics touched on in previous chapters, to provide a guide to areas that deserve additional study. Due to the methodology orientation of the dissertation, many items are mentioned. The main subjects include information system ties to other relief components, including important background factors to consider in implementation planning; topics in simulation and modeling research, and deeper probes into subjects covered in this dissertation.

A well-planned relief study should examine many facets of relief before choosing those areas that seem to promise the greatest rewards for continued effort. This is a common sense approach; knowledge of the overall picture is invaluable when reaching more detailed levels.

Ties to Other Relief Components

It was mentioned in Chapter V that there is a natural overlap between ongoing nutritional surveillance and emergency sampling. A link between the two would be early warning signals of an approaching crisis. Some study has been done on the most useful variables to measure (25). Possible signals include crop forecasts, migrations, food prices and hoarding.

The transportation system will be vital in any plan that requires distribution of available foodstuffs. The transport rate proved to be an important policy item in Chapter IV (see Equations 4.5 and 4.6).

The expected transportation and storage capabilities have a great effect on the amount of foreign aid or imports that can be made available for relief (30).

Using obtained surveillance results for relief field program planning presents an excellent opportunity to link system components. Apparently a well-defined and coordinated survey can provide a "topographical map of malnutrition" for a region (36). Standardized results plotted on a map indicate villages where program efforts need to be concentrated. Additionally, information and program ties with world organization efforts should be explored. The World Health Organization (WHO), United Nations Diseaster Relief Organization (UNDRO), and others are actively pursuing research on relief activities.

Actual implementation of an information system design deserves a much harder look. Corruption, hoarding, a "black market," and the reaction of the people to surveillance techniques are all influences on the information and food allocation systems. Certainly the power concentration in the government will affect the degree of organization and cooperation between relief components. And the degree to which responsibility for the nation's nutrition is handled by varying governmental units will affect implementation feasibility (17). The amount of cooperation from the affected peoples will depend on their faith in the government and on cultural attitudes toward strangers and outsiders.

Strife and prejudice will be enemies of relief. Struggles between rich and poor, between politicians, between races, religions or regions have long been causes of the unequal distribution of food in the world. These conflicts must be taken into account when planning programs and when designing an information system.

Simulation and Modeling

The computer simulation discussed in Part I is a cornerstone of the current approach. Many modifications are possible to make the model conform more closely to real-world behavior; such modifications deserve further study.

Many variables in the current model are aggregations or averages. For example, the urban population is split into three classes, but all rurals are included in one group. A more accurate portrayal would result by identifying the distinct rural groups: landless poor, small and large landowners, etc. (21). Similarly, a breakdown by regions would be useful, especially in the case of only one region of a country struck by famine.

Food types, nutrition and crop patterns are all related when considering variable aggregation. The current model uses one grain equivalent figure and one average nutritional requirement and has no crop breakdowns. This was done in the interest of simplicity, and an effort was made to discern the most important relationships between crops, nutrition and food types. Once one of the above variables is disaggregated, logic generally dictates that others be handled similarly. Suppose that a study of the effects of differing diets was desired. Several food type variables would be required. Production and storage variables might then need to be disaggregated to portray the availability of each food type. And the nutritional calculations would need to be reworked so that the total nutrition picture affected nutritional debt and deaths.

One type of disaggregation that stands out in a famine setting is an age and sex distribution. Children and pregnant women are most susceptible to malnutrition. Food requirements differ with age and body size. A breakdown by sex and three or four age categories would provide added insights to the study of age-dependent surveillance techniques such as the QUAC stick.

One positive result of disaggregation is evident in the use of the substitute objective PERTOT (Equations 8.7). The varying effect of policies on social classes can be studied. It would be very useful to know which policies favor which classes or groups.

It would also be very useful to observe several highly aggregated variables; macroeconomics indicators of the country's stability. Trade balance, food and other prices and the extent of indebtedness acquired to purchase equipment and food are all affected by the management of the relief effort. Addition of a suitable set of equations to the model, as briefly stated in Chapter VII, would allow decision makers to study limiting outside factors on system operations.

A simulation can evaluate alternative allocation strategies but it cannot design them. It has been demonstrated that a strategy of equalizing nutritional debt across an entire population performs better than a price control policy. But neither of these may be feasible in a specific country. Thus there is a great need to devise strategies that are tied to actual situations. Strategy frameworks must be constructed apart from the computer. Computer models can then aid in testing alternative strategies.

Related to strategy design is the modeling problem of decision rules. Nutritional debt, consumption and storage variables are used in the current model as decision variables. Additional factors that could be added would include water level and disease incidence. These would be needed especially if a more detailed model of field programs was desired. It may also be that such factors are best handled outside the model. Possible equations for the use of crop level and harvest time estimate are included in the Appendix computer programs listing. These equations were constructed as an aid in the calculation of average required nutrition (ARNUT) in Chapter IV.

Decision making has been modeled here as a continuous process with constant control parameters in policy equations. The possibility of varying controls with time was discussed briefly in Chapter VI. Allowing control parameters to change at specified intervals leads naturally to the use of dynamic programming (27, Chapter III). Continuous decision making refers to the modeling fact that the control values are computed at each discrete model time interval Δt. As Δt decreases, decisions are made more and more continuously. Compromise would allow for regular decision times, say at weekly intervals. The negative side of dynamic programming is the tremendous increase in the number of distinct control parameters.

It was noted in Chapter VII that a fairly small Δt has been used in this study. A small Δt will lead to large computing costs, especially when more disaggregation and complexities are added. It may be possible to reduce computation time through introduction of a two-step discrete interval process. The model components that require small Δt values can be cycled through many times for each cycle of the bulk of the model. Manetsch and Park describe such an application to delay processes (see Equation 2.18) (40, Chapter 10). For example,

the nutrition and death total calculations require small Δt values, while production, storage and price calculations provide accurate results with coarser time intervals.

Another "time" problem is that of modeling the reversible nutrition process, as mentioned in Chapter II. The cumulative normal probability-of-death function (F2) of Equations 2.3 depends on the initial population nutritional level. A country that faces a famine and then recovers will probably not return to the same initial level. This creates a problem when modeling repeated food shortages (as would occur in chronic food-deficit countries). Thus, a modeling technique is needed to adequately portray this reversible process.

Deeper Probes into Covered Topics

The study of information quality was limited here to delay, frequency and error parameters. The introduction of bias in estimations is distinctly possible, as is the effects of autocorrelated data. The sampling component can easily be altered to model such occurences. In fact, bias is provided for in the original formulation in Chapter III. A more detailed model could examine the sources of information error and delay. The discussion of Chapter V concentrated on the error inherent in data capture and processing. There is also a significant problem in assuring the reliability of data storage.

A simulation model can be used to study many budgeting issues that were touched on in this dissertation. The effect of cost equation changes on optimization results is an additional factor in considering cost versus performance (see Figure 9.3). Since it was shown that optimal policy parameters vary with information quality, a significant topic in the overall relief system is the policy implementation costs $G_2(\underline{P})$ as a function of $\underline{X}$. This was described briefly in Chapter V. $G_2(\underline{P})$ is computed dynamically, so it would be fitting to study this topic when information costs $G(\underline{X})$ were also figured dynamically, so that the same occurrences in the model cycle affect both. The possibility of computing information system costs related to the model cycle rather than as a direct function of $\underline{X}$ was also mentioned in Chapter V.

Related to dynamic cost function modeling is the larger issue of developing a framework for construction of the cost function $G(\underline{X})$. The example used in the current work conveniently avoids some of the more complex problems. Handling the case of multiple system alternatives requires the use of multiple equations to specify $\underline{G}(\underline{X})$. These equations must preserve the uniqueness rule of Chapter V. The approach has the theoretical ability to handle personnel, equipment and time constraints separately from finances. It would be helpful to develop a sub-methodology for such a case, especially when modeling information system links to transport and distribution systems in more detail. In order to build on previous work, it would be useful to develop a solid connection between standard cost/benefit analysis and computer simulations.

Several topics for optimization studies have been suggested in Chapters VIII and IX. Chief among these is an examination of the usefulness of other algorithms, particularly response surface methodologies (48, 60). Another topic would be the different performance objectives' effects on model variables such as population, storage, price, crops, etc. This could constitute an in-depth study of the consequences of stated goals and objectives. If no dynamic cost function is used, the complex algorithm should be modified to check that a given input vector X satisfies constraints, without going through a complete model cycle. This would save computer time, especially on a fuzzy surface.

The facility with which simulation results are produced would be enhanced by the development of several user aids. The framework for the current model is based on a punched-card processing system. Adaptation to a more interactive mode through use of CRT terminals would reduce computer operations time. The program now in use allows for easy changes in certain parameter initial values. An interactive model could prompt for such changes from default values. An additional helpful feature would be to also prompt for the particular policy alternative desired. As mentioned in Chapter V, consumption surveys are not likely to be practical. A model that allows the exclusion of such a variable would be useful. Similarly, it would save time if the program allowed for a sensitivity testing mode, where changes in inputs are specified and the appropriate percentage change in system performance is calculated as one of the program outputs. Such a feature could be helpful in any computer simulation. In particular, the sensitivity tests in Chapters IV, VI, VII and VIII would all have been accomplished much more quickly.

Filters and predictors to fit the varied estimation problems in famine relief are needed because variable estimation is a key problem. As mentioned in Chapter VI, the α-β tracker and the use of polynomial smoothing as a predictor are possible starting points.

There are many economic and personal factors affecting relief efforts that deserve study. Again, wisdom is needed for productive selection of topics. Certainly research on consumption habits preceding and during a famine is a top priority. As light is shed on the likelihood of hoarding, the tendency toward self-rationing and the starting point for hand-to-mouth feeding, the model consumption equations can be further tied to reality. Price level, the rate of inflation, international grain costs and supply are some of the macroeconomic factors that will impinge on relief. A study comparing the effect of these factors on relief performance would help to design ongoing surveillance.

Summary

One of the goals of this dissertation was to provide a framework for future study. As this section shows, many items logically connect to the information system design problem; much additional work is needed. Man has a responsibility to study these questions because he must be a wise steward of what has been given to him.

The next steps are logical extenstions of the "proposed methodology" nature of this dissertation: evaluation of the approach by the intellectual community and adaptation of the model and approach to a real-world situation.

APPENDICES

APPENDIX A

NUMERICAL COST COEFFICIENTS

NUMERICAL COST COEFFICIENTS

There exists a large jump from the theoretical equations of Chapter V to the hard numbers presented in Chapter IX. This appendix is intended to fill part of that gap by presenting the numerical coefficients used in the simulation work. The same data is also available in the computer program of Appendix B, but is much less accessible there.

Equations will be presented here without complete explanations. The rationale and variable definitions can be found in Chapter V, Equations 5.18-5.36.

The goal of the cost function is to determine information system costs based on information quality parameters $\underline{X}$. Equation A.1 (5.36) is the final step, stating that total costs will equal the sum of transmission cost, nutritional survey cost, consumption survey cost, and private storage survey cost.

$$\text{COSTGX} = \text{CDELF} + \text{CSN} + \text{CSC} + \text{CSS} \tag{A.1}$$

The transmission cost is most easily computed. It is an interpolation problem using the function of Figure 5.1. The four points of the curve and their corresponding system descriptions are listed in Table A.1. The cost parameters CDEL in Table A.1 were derived from Equations A.2, A.3, A.4 (5.33), and A.5 (5.34). The constants used in used in the simulation are given in Table A.2.

Table A.1 Transmission Interpolation Points

Point	System Description	DEL (Yrs)	CDEL (million won)
1	Current microwave system	≥.038	126.6
2	Two-way transceivers	.023	128.7
3	Base microcomputers	.015	153.3
4	Renovation of UHF network	.011	193.3
-	New microwave network	<.011	193.3 + (.011-DEL)* 10^{10}

Table A.2 Transmission System Cost Components

System (i) / Component	Fixed Cost (0)	Current Microwave base (1a)	Current Microwave links (1b)	Two-way Transceivers (2)	Base Micro-computer (3)	UHF renovation (4)
UEQ (#)	1	30	1	75	30	1
WEQ(1000 won)	5,000,000	800	10,000	50	400	500,000
MAINT (%)	.25	.25	.25	.25	.25	.25
PDEP (%)	.15	.30	.35	.30	.30	.15
PUS (%)	.05	.5	.2	1.0	1.0	.2
UPR (#)	20	60		-	30	-
WPR(1000 won)	800	600		-	600	-
TPR(1000 won)	-	-		-	-	-
PRPUS (%)	.05	.5		-	1.0	-

$$CDEL_0 = CEQ_0 + CPR_0 \quad (A.2)$$

$$CDEL_i = CDEL_{i-1} + CEQ_i + CER_i \text{ , } i=1,2,3,4 \quad (A.3)$$

$$CEQ_i = UEQ_i * WEQ_i * (MAINT_i + PDEP_i) * PUS_i \text{ , } i=0,1,2,3,4 \quad (A.4)$$

$$CPR_i = UPR_i * (WPR_i + TPR_i) * PRPUS_i \text{ , } 1=0,1,2,3,4 \quad (A.5)$$

Survey costs are calculated using the form of Equation A.6 (5.18), with details as presented in Equations A.7 (5.21) and A.8 (5.22 and 5.26). Note that A.7 provides the needed number of samples, given allowable variance, and A.8 calculates the cost of one survey. Recall that CSUR and n are computed with the assumptions that each population class represents a separate survey and the four regions are the statistical sampling strata. If the classes and regions are considered together as sixteen separate strata, the formulae A.7 and A.8 would not allow the S_j's to be taken outside the inner summation signs.

$$CS = CFIX + CSUR / SAMP \quad (A.6)$$

$$n = \frac{1}{V} * \sum_{j=1}^{M} S_j^2 * \left(\sum_{h=1}^{L} W_h / \sqrt{C_{hj}^*} \right) * \left(\sum_{h=1}^{L} W_h / \sqrt{C_{hj}^*} \right) \quad (A.7)$$

$$CSUR = C_0 + ((SAMP\text{-}COST) / V) * \sum_{j=1}^{M} S_j^2 * \left(\sum_{h=1}^{L} W_h \sqrt{C_{hj}^*} \right)^2 \quad (A.8)$$

Chapter V provides for four divisions of the country (L=4) and four population classes (M=4). Costs (C_{hj}) are figured on two breakdowns, by region and by class, while standard error (S_j) varies only by class. The basic core of data is given in Tables A.3. Costs C_{hj}^* in Table A.3 are relative indices of cost size by class and region and are multiplied by appropriate per-unit sampling costs to obtain the cost for a particular survey type. Note that some mathematical

Table A.3a Relative Costs and Population Percentages for Surveillance Calculations

Class $\vec{j}$ / Region h↓	C^*_{hj} Relative Sampling Costs: Urban poor No relatives 1	Urban poor With relatives 2	Urban Rich 3	Rural 4	Wh Population Percentages
Region 1	1	1	1.2	.9	.233
Region 2	1	1	1.2	.9	.301
Region 3	1.1	1.1	1.32	.99	.198
Region 4	1.2	1.2	1.44	1.08	.268

Table A.3b Standard Error and Per-unit Sampling Costs for Surveillance Calculations

Class / Type of Surveillance	Sj Standard Error: Urban poor No relatives 1	Urban poor With relatives 2	Urban Rich 3	Rural 4	Sampling Cost (won)
Nutrition (SN)	.03	.03	.045	.045	200
Consumption (SC)	.3	.3	.35	.35	1,200
Storage (SS)	-	-	-	.2	800

economies are possible if the C^*_{hj} are employed in the body of the calculations and the per-unit costs are multiplied at the end.

Two further items must also be computed. Variance V is influenced by Equation A.9 (5.28). And fixed costs are calculated as in Equation A.10 (5.27). The appropriate constants are given in Table A.4.

$$SDT_i = STP_i \; * \; VAVG_i \; (SDT_i^2 = V_i) \tag{A.9}$$

$$(SDT_i^2 = V \; ; \; SDP_i = SDRC \text{ or } SDRS)$$

$$CFIX_i = TEAMS_i * (TRAIN_i + EQ_i * PMNT_i) \tag{A.10}$$

Using all of the above values, the following simplified, approximated equations result (A.11-A.16). These equations are extremely useful in estimating partial or total costs for given levels of information quality. The figures for Table 9.4 are derived from an application of these equations to the raw averages of Table 9.3.

$$n_{nutrition} = .0059/SDND^2 \tag{A.11}$$

$$n_{consumption} = 10.6/SDRC^2 \tag{A.12}$$

$$n_{storage} = 9.2/SDRS^2 \tag{A.13}$$

$$CSUR_{nutrition} = 875{,}000 + (5000 + \frac{1.297}{SDND^2}) \; / \; SAMPT \tag{A.14}$$

$$CSUR_{consumption} = 1{,}312{,}500 + (5000 + \frac{14058}{SDRC^2}) \; / \; SMPRC \tag{A.15}$$

$$CSUR_{storage} = 875{,}000 + (5000 + \frac{7086}{SDRS^2}) \; / \; SMPRS \tag{A.16}$$

Table A.4 Fixed Cost
Parameters and Variance for Total Cost Calculations

Survey Type	Fixed Cost Parameters: Teams (#)	Train (1000 Won)	EQ (1000 Won)	PMNT (%)	Variance VAVG
Nutrition	25	10	20	1.25	1.0
Consumption	25	30	18	1.25	0.2
Storage	25	20	12	1.25	.066

APPENDIX B

FORTRAN COMPUTER PROGRAM

```
      PROGRAM MAIN(INPUT=65,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT,
     1  DEBUG=OUTPUT)
      COMMON /BLOCK/  DUR,DT,DETPRT,SELPRT,BEGPRT,PRTCHG,PRTVL1,PRTVL2,
     1                G1,GSTKD,GNSLS,CG1,CG2,CG3,TPUNDO,CG5,TPUND1,GSU1
     2               ,GSRD,GSUD,GCONMX,GDE,WF,RK1,RK2,RDE,CM1,CG7,CGP,
     3                CG20,CG21,CG22,CG23,CG24,CG25,CG26,CG27,CG28,
     +                CG29,CG30,CG31,CG32,CG33,CG34,CIG1,PRIPOP,PRGPC,
     +                TSEA,DELINF,CG35,CG36,SDND,SDRC,DELD,DELRC,SAMPT,
     +                BIASD,BIASRC,VARTME,MONPR,SMPRC,SMPUS,DELUS,SDUS,
     +                BIASUS,SMPRS,DELRS,BIASRS,SDRS,CG60,CG61,CRUT,
     +                CG70,CG71,CG72,CG73,CG74,CG75,CG76,CG77
      COMMON /GOVTE/   GIMPO,GSRU,EMFDG,TANUTD,GCONRF,GPSTK,GSP,GSU,
     +                 GIMP,GFPPU,GEAL,GCONR,GIMPMX,TPUND,CG4,CG6,
     +                 CHI,ER,PWLD,FSTORM,RATWT,UPWT,AEUNDP,AEPCNU,
     +                 RDBJ,UOBJ,ERCNTU(3),ERCNTR,GSLSDU,GPSTRD
     +         ,EPCONR,EPCONU(3),EIMP,EPU(3),GUSTRD(3),ERNUT(3),ERNUTR,
     +          ECHAFF
      COMMON /URBANE/ RNUTP(3),FR(3),PDTH(3),PDTHM1(3),ANTDP1(3),
     +                DTHSM(3),XFU1(3),FU1(3),PCONSU(3),CONSU(3),
     +                USTORD(3),DEMP(3),AINC(3),TDTHSM(3),USTOR(3),
     +                EUSTOR(3),EATNDP(3)
      COMMON /RURALB/ YLD(2),OPUT(3),A1(2),NT,RNUTPR,RBR,PDTHR,PDTHR1,
     +                RDTHSM,RDR,XFR1,FR1,PCONSR,CONSR,FR3,RSTORD,
     +                RD2,PR,TRDTHM,RNUTDP,PFDRN,RH1,RH2,PANUTD,
     +                NTSH(2),R1(20),R2(10),RANTDP,EMFSU,RNTDP1,FR2,
     +                ERSTOR,ERNTDP
      COMMON /MKTE/   DEM,SUP
      COMMON /SYSVAR/ ANUTDP(3),RSTOR,PFD,PFDR,T,MIGIN(3),MIGOUT(3),
     +                UPUP(3),EMFD(3),DPFRDT,RSUP,PSALES,EMFDGU(3),
     +                GSLS,GSLSD,UDEM(3),DPFDDT,PU(3),ARMUT,EDPC,
     +              EDPCS,EMERG,ESTGDF,ETDSTG,ETPOP,TPOP,TTSH,EMFINT
     +             ,RNUTPN,RCNTR,EMFDGL(3),RCNTU(3)
      REAL MIGIN,MIGOUT
      COMMON /COSTSB/ GCON,EMFTOT,GSLTOT,EMTRAN,EMSTOR,GIMTOT,CGSLS,
     2                CGCON,CEMFD,CPROG,CGSRU,CSTOR,CGIMP,COSTGP,CDELD,
     3                 CSURN,CSURCU,CSURRU,CYFSUR,SNUMNT,SNUMCT,SNUNS,
     4                 SNUMN(4),SNUMC(4),COSTGX,COSTOT
      COMMON /VAR/ NXNS,XEARM(10),VARXM(10),XNM(10),NVARV
      DIMENSION   NMVAR(80)
      DIMENSION   INTF(10)
      DIMENSION   ERCD(4)
      DIMENSION   IDXM(10)
      DIMENSION   RUINIT(3)
CS    ARRAYS
C
      DATA NVAR /80/
C
      DATA NAMVAR / 3HDUR,     2HDT,      6HDETPRT,  6HSELPRT,  6HBEGPRT,
     1              6HPRTCHG,  6HPRTVL1,  6HPRTVL2,  2HG1,      5HGSTKD,
     2              5HGNSLS,   3HCG1,     3HCG2,     3HCG3,     6HTPUNDO,
     3              3HCG5,     6HTPUND1,  4HGSU1,    4HGSRD,    4HGSUD,
     4              6HGCONMX,  3HGDE,     2HWF,      3HRK1,     3HRK2,
     5              3HRDE,     3HCM1,     3HCG7,     3HCGP,
     6              4HCG20,    4HCG21,    4HCG22,    4HCG23,    4HCG24,
     7              4HCG25,    4HCG26,    4HCG27,    4HCG28,    4HCG29,
     8   4HCG30,  4HCG31,  4HCG32,  4HCG33,  4HCG34,
     9  4HCIG1,   6HPRIPOP,5HPRGPC,  4HTSEA,   6HDELINF,4HCG35,   4HCG36,
     +  4HSDND,   4HSDRC,   4HDELD,   5HDELRC,  5HSAMPT,  5HBIASD,  6HBIASRC,
     1  6HVARTME,5HMONPR,  5HSMPRC,  5HSMPUS,  5HDELUS,  4HSDUS,   6HBIASUS,
     2  5HSMPRS,  5HDELRS,  6HBIASRS,4HSDRS,   4HCG60,4HCG61,   4HCRUT,
     3  4HCG70,   4HCG71,   4HCG72,   4HCG73,   4HCG74,   4HCG75,   4HCG76,
     4  4HCG77 /
C
C
      DATA MIGIN,MIGOUT / 6*0.0 /
      READ900,NRUN
C
C        BEGIN RUN LOOP
C
      DO 500 IRUN=1,NRUN
C
      READ 900, MONRUN
C
C                       DEFINE PARAMETERS UNCHANGED THRU SIMULATION RUN
C
C
C        RUN PARAMETERS
      DUR = 1.0000001
      DT = .002
      DETPRT = 0.5
      SELPRT=1.
      BEGPRT = .5
```

```
      PRTVL1 = .5
      PFTCHG = 2.
      PRTVL2=.5
C          DATA FOR RURAL
      WF=.65
      RK1 = 5.
      RK2 = .2
      RDE=1.
C
C          DATA FOR MARKET
C
      CM1=7.
C
C          DATA FOR GOVT
      GIMPMX=2.E+06
C          GIMPMX=MAX GOVT IMPORT RATE-MT/YR
      G1=5.E+06
C          GI=GOVT IMPORT ORDER PARAM-MT/YR-MT
      GSTKD=2.E+06
C          GSTKD=DESD STOCK IMPORT TARGET-MT
      GNSLS=2.E+06
C          GNSLS=NORMAL LEVEL OF DOMESTIC SALES-MT/YR
      CG1 = 50.
C          CG1=GOVT SHIPPING RATE RURAL-URBAN WAREHOUSES (MT/YR-MT)
      GSRD = 20000.
C          GSRD=GOVT RURAL STOCK LEVEL DSD
      GSUD = 40000.
C          GSUD=GOVT URBAN STOCK DSD-MT
      CG6=.[illegible]
C          CG6=DELAY IN CONFISCATING FOOD (YRS)
      CG3=0.
C          CG3=GOVT EMG RELEASE RATE-MT/YR-MT
      TPUND0=.10E+06
C          TPUND0=THRHLD URBAN NUT DEBT FOR EMERG RELEASES BY GOVT-MT
      CG5=0.
C          CG5=GOVT CONFISCATION RATE-MT/YR-MT
      TPUND1=.20E+06
C          TPUND1=THRHLD URBAN NUT DEBT FOR GOVT CONFISCATION-MT
      GCONMX=15.E+06
C          GCONMX=MAX GOVT CONFISATION RATE-MT/YR
      CG7=0.
      CG8=30.E+06
      RSTORM = .255
C          RSTORM=MIN LVL OF RURAL STORG FOR DET OF CONFISCATION?
      PWLD=400.
C          PWLD=WORLD PRICE-$/MT
      ER=400.
C          ER=ECHANGE RATE WON/$
      CHI=16[illegible]00.
C          CHI=COST OF HOLDING INVENTORY - WON/MT-YR.
C
C                                    POLICY PARAMETERS
C
C
      GDE = .02
      CG2 = 1.5
      CG4 = 0.
      CG20 = .1
      CG21 = 0.0
      CG22 = .1
      CG23 =  0.
      CG24 = 14.
      CG27 = 18.
      CG30 = 5.5
      CG31 = 0.
      CG32 = 5.0
      CG33 = .012
      CG34 = 0.0
      CG35 = .01
      CG36 = 2.
      CG28 = 1.0
      CG29 = 1.0
C
      CG25 = 3.9
      DELUS = .65
      DELRS = 1.
      GSU1 = .9
C
      DELPC = 0.0                 PRICE LIMIT
C
      VARTME = .2E7
C
```

```
C                                  COST PARAMETERS
      CG5   = 1.
      CG6   = 1.
      C[illegible] = 25.0.
      CG7   = .25
      CG71  = .011
      CG72  = 200.
      CG73  = 1200.
      CG74  = 900.
      CG75  = .015
      CG76  = .025
      CG77  = .035
C
C        INITIALIZE RECURSIVE CALCULATION OF MEANS AND VARIANCES
C
      DO 179 KK=1,10
      XBARM(KK) = 0.0
      VARXM(KK) = 0.0
  179 XNP(KK) = 0.0
      NVARV = 10
      NONPR = 1.
C
C                                  PARAMETERS FOR SAMPLING COMPONENET
      SDRS = 0.0
      SVPUS = .002
      SD[illegible] = 0.0
      SDRC = 0.0
      SDRS = 0.0
      DELD = .004
      SAMPT = .002
      SMPRC = .002
      SMPRS = .002
      TDEAS = 1795003.
      TNBAS = 87395.
      CG26 = .75
      BIASD = 0.0
      BIASRC = 0.0
      BIASUS = 0.0
      BIASRS = 0.0
C                                  PARAMETERS FOR INT"L FOOD AID
      TSEA=.1
      DELINF=.1
      CIG1=0.
      PRIPOP=1.E+06
      PRGPC=0.
C
C         READ RUN PARAMETERS
C
      WRITE(2,901) IRUN
      CALL NAMLST(NAMVAR,NVAR,ERROR)
      IF(ERROR.NE.0.) STOP
      NITER = DUR/DT +.000000000001
      ALP = CG26
      BET = 1. - ALP
C                                            BEGIN MONTE CARLO LOOP
C
C
      DO 450 MRUN = 1,MONRUN
      NXNS = MRUN
      IF(SELPPT.NE.0.) PRINT 501
C                                      DEFINE INITIAL CONDITIONS
C
C                                  DATA FOR GOVT
      GBAL=160.E+09
      TPUBD=0.
      GPSTK = .15E6
      GSR=.1E+06
      GSU=.5E+06
      NP=3
C          NP=NUMBER OF URBAN POPULATION GROUPS
C          URBAN INITIAL CONDITIONS
      PU(1)=[illegible].E+06
      PU(2)=6.E+06
      PU(3)=[illegible].E+06
      DO 551 II=1,NP
      TOTFSM(II)=0.
      ANUTDP(II) = .1E-10
      PUINIT(II) = PU(II)
  551 USTCK(II)=PU(II)*.36*.228
      ANUTDP(3)=-.03
C
```

```
C          DATA FOR RURAL
      NT=1
      RNUTDP = .1E-10
      RNTDP1=0.
      EMFSU=0.
      PFOR=100000.
      PFORN=PFOR
      TROTHM=0.
      DO 648 JJ=1,10
      R1 (JJ)=0.
  648 R2 (JJ)=0.
      RH1=0.
      RH2=0.
      PR=16.E+06
      PRINIT = PR
      RSTOR = 2.0E6
      ERSTOR = 2.0E6
      PANTDP=0.
      PANUTD=0.
C
      DPFRDT=0.
      PCONSR=.182
      GCONR = 0.0
C          DATA FOR MARKET
      PFD=115000.
C
C          PARAMETERS AND IC"S FOR INT"L FOOD AID
      EMERG=0.
      EMERGP=0.
      NIA=0
      EMFINT=0.
      DO 189 J1=1,10
  189 RINTF(J1)=0.
      ESTGDF=0.
C          END OF PARAMETERS AND IC"S FOR INT"L FOOD AID
C
      T = 0.
      PRTIME = BEGPRT
      PRTVL = PRTVL1
      TNMAX = 0.
      TNMIN = 0.1E6
      NTSH(1)=.75/DT+.00001
      NTSH(2)=.55/DT+.00001
      NTSEA=TSEA/DT+.0001
C
C          BEGIN TIME LOOP
C
      DO 400 ITER=1,NITER
      T = T+DT
C          EQUATIONS FOR INTERNATIONAL FOOD AID
      EMERGP=EMERGP+EMERG
      NIA=NIA+1
      EFINTU=CIG1*ESTGDF+PRIPOP*PRGPC/PWLD
C          EFINTU=UNLAGGED INTERNATIONAL FOOD AID (MT)
      FSINT=0.
      IF (NIA.EQ.NTSEA) FSINT=EFINTU/DT
      CALL DELDT(FSINT,EMFINT,RINTF,DELINF,2,DT,10)
  288 CONTINUE
C
C          CALL MODEL
      CALL URBAN
      CALL RURAL
      CALL GOVT
      CALL MKT
C
      TNUTD = TANUTD + RNUTDP*PR
      IF(TNUTD.LT.TNMAX) GO TO 75
      TNMAX = TNUTD
      TTMAX = T
   75 CONTINUE
      IF(T.LT..6) GO TO 77
      IF(TNUTD.GT.TNMIN) GO TO 77
      TNMIN = TNUTD
      TTMIN = T
   77 CONTINUE
C
      IF(T.LT.PRTIME-.0000001) GO TO 200
C
C          PRINT RESULTS
C
      IF(T.GT.PRTCHG-.0000001) PRTVL=PRTVL2
```

```
      PRTIME = T + PRTVL
      TDETH = TDTHSM(1)+TDTHSM(2)+TDTHSM(3)+TRDTHM
      TNUTDP = TNUTD/TPOP
      TSTG = RSTOR + USTOR(1) + USTOR(2) + USTOR(3)
      IF(SELPRT.EQ.0.)GO TO 100
C
C          SELECTED OUTPUT
C          PRINT STATEMENTS FOR SELECTED OUTPUT
      PRINT 902, T,TRDTHM,TDTHSM,TDETH,TNUTD,TNUTDP,TPOP,TSTG
      IF(DUR.GT.PRTIME) GO TO 100
      PERCD(1) = TRDTHM/PRINIT
      DO 95 JT=1,3
   95 PERCD(JT+1) = TDTHSM(JT)/PUINIT(JT)
      STYNUM = ALP*(TDETH-TDBAS)/TDBAS + BET*(TNUTD-TNBAS)/TNBAS
      PRINT 903, PERCD
      CALL COSTS
C
  100 CONTINUE
      IF(DETPRT.EQ.0.) GO TO 200
C
C                         DETAILED OUTPUT
C
      PRINT 905, T
      PRINT 906, PU,PR,TPOP,ETPOP,ERCNTU,ERCNTR
      PRINT 907, ANUTDP,RNUTDP,RCNTU,RCNTR
      PRINT 908, EATNDP,ERNTDP,AEUNDP,AERCNU,GSU,GSR,GEAL
      PRINT 909, USTOR,RSTOR,TPURD,GCONR,GSLSD,EMFDG
      PRINT 910, EUSTOR,ERSTOR,GRSTRD,GCONFP,GSLSDU,EMFDGU(1),EMFDGU(2)
      PRINT 911, ARNUT,EDPC,EDRCS,ESTGDF,ETDSTG,EMERG
      PRINT 912, GSRU,GFRRU,GSLS,GIMP,EMFD(2),XFU1
      PRINT 913, PCONSU,PCONSR,RNUTP,RNUTPR
      PRINT 920, EPCONU,EPCONP,UPUR,PSALES,EIMP
      PRINT 921, GUSTRD,PFD,FFDR,GCON,EMFTOT
       PRINT 922, PANUTD,PANTDP,XFR1,FR1,CONSR,RH1,RH2,EMFSU,ECHARF
      PRINT 931, GSLTOT,EMTRAN,EMSTOR,GIMTOT,CGSLS
  200 CONTINUE
  400 CONTINUE
C
C               RUN DURATION COMPLETE. CHECK FOR MONTE CARLO PRINTS
C
      IF(MONPR.EQ.0) GO TO 450
      XNM(1) = COSTGP
      XNM(2) = COSTGX
      XNM(3) = STYNUM
      XNM(4) = CGSLS
      XNM(5) = TDETH
      XNM(6) = TNUTD
      XNM(7) = PERCD(1)
      XNM(8) = PERCD(2)
      XNM(9) = PERCD(3)
      XNM(10) = PERCD(4)
      IF(NXNS.GT.1) GO TO 307
      DO 306 JJ=1,NVARV
      XBARM(JJ) = XNM(JJ)
  306 CONTINUE
      GO TO 309
  307 CALL VARCAL
  309 DO 319 JJ= 1,NVARV
  319 SDXM(JJ) = SQRT(VARXM(JJ))
  315 PRINT 915, NXNS,(SDXM(J),J=1,NVARV) ,(XBARM(J),J=1,NVARV)
  450 CONTINUE
  500 CONTINUE
      STOP
C
C          FORMAT STATEMENTS
  900 FORMAT(I2)
  901 FORMAT(1H0,4X,*TIME*,3X,6HTRDTHM,15X,*TDTHM(1-3)*,16X,5HTDETH,
     2          7X,5HTNUTD,7X,6HTNUTDP,6X,4HTPOP,8X,4HTSTG,/)
  902 FORMAT(1H ,3X,F5.3,9E12.4)
  903 FORMAT(1H ,6X,4F12.3)
  904 FORMAT(1H0,*THE LARGEST VALUE OF TNUTD IS *,E12.4,*  AT TIME *,
     2    F6.3,/,* THE SMALLEST VALUE OF TNUTD IS*,E12.4,*  AT TIME *,
     3    F6.3)
  910 FORMAT(1H0,9X,5HCGCON,7X,5HCEMFD,7X,5HCGSRU,7X,5HCSTOR,7X,
     2          5HCGIMP,7X,5HCDELD,7X,5HCSUPN,7X,6HCSUPCU,6X,6HCSUPRU,6X,
     3          6HCYRSUR,/,5X,10E12.4)
  911 FORMAT(1H0,11X,6HSNUMNT,6X,6HSNUMCT,6X,5HSNUMS,/,7X,3E12.4)
  901 FORMAT(1H0,/,1H0,*NON-DEFAULT PARAMETER VALUES FOR RUN*,I3)
  905 FORMAT(1H0,*DETAILED OUTPUT VARIABLES AT TIME*,F6.2)
  906 FORMAT(1H0,9X,5HPU(1),7X,5HPU(2),7X,5HPU(3),7X,2HPR,10X,4HTPOP,8X,
     2          5HETPOP,7X,9HERCNTU(1),3X,9HERCNTU(2),3X,9HERCNTU(3),3X,
```

```
     3        6HEHRCNTR,/,5X,10E12.4)
  917 FORMAT(1H0,11X,9HANUTDP(1),3X,9HANUTDP(2),3X,9HANUTDP(3),3X,
     2        5HRNUTDP,18X,8HRNCTU(1),4X,8HRCNTU(2),4X,8HRCNTU(3),4X,
     3        6HRCNTR,/,7X,4E12.4,12X,4E12.4)
  908 FORMAT(1H0,13X,9HEATNDP(1),3X,9HEATNDP(2),3X,9HEATNDP(3),3X,
     2        6HERNTDP,6X,6HAEUNDP,6X,6HAERCNU,6X,3HGSU,9X,3HGSR,9X,
     3        4HGEAL,/,9X,9E12.4)
  909 FORMAT(1H0,15X,8HUSTOR(1),4X,8HUSTOR(2),4X,8HUSTOR(3),4X,5HRSTOR,
     2        7X,5HTFUNC,7X,5HGCONR,7X,5HGSLSD,7X,5HEMFDG,/,11X,8E12.4)
  910 FORMAT(1H0,17X,9HEUSTOR(1),3X,9HEUSTOR(2),3X,9HEUSTOR(3),3X,
     2        6HERSTOR,6X,6HGRSTRD,6X,6HGCONSP,6X,6HGSLSDU,6X,
     3        9HEMFDGU(1),3X,9HEMFDGU(2),/,13X,9E12.4)
  911 FORMAT(1H0,19X,5HARNUT,7X,4HEDPC,8X,5HEDPCS,7X,6HESTGDF,6X,
     2        6HETDSTG,6X,5HEMERG,/,15X,6E12.4)
  912 FORMAT(1H0,21X,4HGSRU,8X,5HGFRFU,7X,4HGSLS,8X,4HGIMP,8X,7HEMFD(2),
     2        5X,7HXFU1(1),5X,7HXFU1(2),5X,7HXFU1(3),/,17X,8E12.4)
  913 FORMAT(1H0,9X,9HPCONSU(1),3X,9HPCONSU(2),3X,9HPCONSU(3),3X,
     2        6HPCONSR, 6X,8HRNUTP(1),4X,8HRNUTP(2),4X,8HRNUTP(3),4X,
     3        6HRNUTPR,/,5X,8E12.4)
  915 FORMAT(1H0,*STANDARD DEVIATIONS AND MEANS FOR*,I3,*RUNS*,/,
     2         1H0,11X,6HCOSTGP,6X,6HCOSTGX,6X,6HSTYNUM,6X,5HCGSLS,7X,
     3         5HTDETH,7X,5HTNUTD,7X,*PERCD...RURAL, URBAN1, URBAN2, *,
     4         *URBAN3*,/,9X,10E12.4,/,9X,10E12.4)
  920 FORMAT(1H0,11X,9HEPCONU(1),3X,9HEPCONU(2),3X,9HEPCONU(3),3X,
     2        6HEPCONP,6X,7HUPUR(1),5X,7HUPUP(2),5X,7HUPUR(3),5X,
     3        6HRSALES,6X,4HEIMP,/,7X,9E12.4)
  921 FORMAT(1H0,13X,9HGUSTRD(1),3X,9HGUSTRD(2),3X,9HGUSTRD(3),3X,
     2        3HPFD,9X,4HPFDR,8X,4HGCON,8X,6HEMFTOT,/,9X,7E12.4)
  922 FORMAT(1H0,15X,6HPANUTD,6X,6HPANTDP,6X,4HXFP1,8X,3HFR1,9X,
     2        5HCONSR,7X,3HRH1,9X,3HRH2,9X,5HEMFSU,7X,6HECHARF,/,11X,
     3        9E12.4)
  931 FORMAT(1H0,17X,6HGSLTOT,6X,6HEMTRAN,6X,6HEMSTOR,6X,6HGIMTOT,6X,
     2         5HCGSLS,/,13X,5E12.4)
C
      END
```

```
      SUBROUTINE URBAN
      COMMON /URBANB/ RNUTP(3),BR(3),PDTH(3),PDTHM1(3),ANTDP1(3),
     +                DTHSM(3),XFU1(3),FU1(3),PCONSU(3),CONSU(3),
     +                USTORD(3),DEMP(3),AINC(3),TDTHSM(3),USTOR(3),
     +                EUSTOR(3),EATNDP(3)
      COMMON /BLOCK/ DUR,DT,DETPRT,SELPRT,BEGPRT,PRTCHG,PRTVL1,PRTVL2,
     1               G1,GSTKD,GNSLS,CG1,CG2,CG3,TFUND0,CGF,TFUND1,GSU1
     2              ,GSPD,GSUD,GCONMX,GDE,WF,RK1,RK2,RDE,CM1,CG7,CGP,
     3               CG20,CG21,CG22,CG23,CG24,CG25,CG26,CG27,CG28,
     +               CG29,CG30,CG31,CG32,CG33,CG34,CIG1,PRIPOP,PRGPC,
     +               TSE4,DELINF,CG35,CG36,SDND,SDRC,DELD,DELRC,SAMPT,
     +               BIASD,BIASRC,VARTME,MONPP,SMPRC,SMPUS,DELUS,SDUS,
     +              'BIASUS,SMPRS,DELRS,BIASRS,SDRS,CG60,CG61,CRUT,
     +               CG70,CG71,CG72,CG73,CG74,CG75,CG76,CG77
      COMMON /SYSVAR/ ANUTDP(3),RSTOR,PFD,PFDR,T,MIGIN(3),MIGOUT(3),
     +                UPUR(3),EMFD(3),DPFRDT,RSUP,RSALES,EMFDGU(3),
     +                GSLS,GSLSD,UDEM(3),DPFDDT,PU(3),ARNUT,EDPC,
     +               EDPCS,EMEFG,ESTGDF,ETDSTG,ETPOP,TPOP,TTSH,EMFINT
     +              ,RNUTPN,RCNTR,EMFDGL(3),RCNTU(3)
      REAL MIGIN,MIGOUT
      DIMENSION ANDPM1(3),ANTDPM(3),DR(3),PCI(3),VALD(6),VALFU1(7)
      DATA(VALFU1(J),J=1,7)/0.,.5E,.9,.95,.99,1.0,1.0/
      DATA UK6/30./
      DATA UK4,UK5,RNUTPN /2.92  ,.152  ,.228  /
C         B1=NORMAL BIRTH RATE-PROP OF TOT POP/YR
      DATA  B1,B2 /.04,1./
      DATA VALD(1),VALD(2),VALD(3),VALD(4),VALD(5),VALD(6)/0.,.05,.25,
     1.5,.85,1.0/
C         DRO=NORMAL DEATH RATE
      DATA DRO /.02 /
      DATA YDSTOR,USTORM / .06,.5 /
      DATA UK1,UK2 /100.,100./
      DATA (PCI(I),I=1,3) / 90000. ,  90000. , 600000. /
      DATA UK3/.5/
      DATA TFSUP,TFEAT / .002,.003 /
      IF (T.GT.DT) GO TO 9
      DO 8 II=1,3
      ANTDPM(II)=0.
      ANDPM1(II) = .1E-10
      UPUR(II)=0.
      EMFD(II)=0.
      EMFDGL(II) = 0.
    8 EMFDGU(II)=0.
    9 CONTINUE
      DO 1 I=1,3
C         COMPUTE RATE VARIABLES
      RNUTP(I)=AMAX1((RNUTPN    -UK4*ANUTDP(I)),UK5)
C         COMPUTE URBAN PER CAP CONS--PCONSU
      XFU1(I)=USTOR  (I)/(RNUTP(I)*PU(I))
      FU1(I)=TABLIE(VALFU1,0.,.01,6,XFU1(I))
      PCONSU(I)=(RNUTPN+UK6*ANUTDP(I))*FU1(I)
      IF  (ANUTDP(I).LT.0.) PCONSU(I)=RNUTP(I)*FU1(I)
      PCONSU(I)=AMIN1(PCONSU(I),.4)
      IF(XFU1(I).LT.TFSUP) PCONSU(I) = USTOR(I)/(PU(I)*TFEAT)
      IF(USTOR(I).LT.USTORM) PCONSU(I) = 0.
      CONSU(I)=PCONSU(I)*PU(I)
      BR(I)=AMIN1(AMAX1((B1*(1.+B2*((PCONSU(I)-RNUTP(I))/RNUTP(I)))),0.)
     1,B1)*PU(I)
      ANTDPM(I)=AMAX1(ANTDPM(I),ANUTDP(I))
      PDTH(I)=TABLIE(VALD,0.,.01,5,ANTDPM(I))
      PDTHM1(I)=TABLIE(VALD,0.,.01,5,ANDPM1(I))
      ANTDP1(I)=ANUTDP(I)
      ANDPM1(I)=ANTDPM(I)
      DTHSM(I)=AMAX1((PDTH(I)-PDTHM1(I))*(PU(I)+TDTHSM(I)),0.)
      DR(I)=DTHSM(I)/DT+DRO*PU(I)
C         COMPUTE URBAN FOOD DEMAND
      USTORD(I)=YDSTOR*RNUTP(I)*PU(I)
      DEMP(I)=(RNUTP(I)+UK1*ANUTDP(I))*PU(I)+UK2*(USTORD(I)-USTOR(I))
     1          -EMFD(I)-EMFDGL(I)
      IF(ANUTDP(I).LT.0.) DEMP(I) = RNUTP(I)*FU(I) +
     2                               UK2 *(USTORD(I)-USTOR(I))
      AINC(I)=PCI(I)*PU(I)
      UDEM(I)=DEMP(I)
      IF  (DEMP(I)*PFD.GT.UK3*AINC(I)) UDEM(I)=UK3*AINC(I)/PFD
      UDEM(I) = AMAX1(UDEM(I),0.)
      RCNTU(I) = RNUTP(I)-PCONSU(I)
C         COMPUTE STATE VARIABLES
      PU(I)=PU(I)+DT*(BR(I)-DR(I)+MIGIN(I)-MIGOUT(I))
      PU(I) = AMAX1(PU(I), .1E-10)
      TDTHSM(I)=TDTHSM(I)+DTHSM(I)
      ANUTDP(I)=ANUTDP(I)+DT*(RNUTP(I)-PCONSU(I))
      USTOR(I) = USTOR(I)+DT*(UPUR(I)-CONSU(I)+EMFD(I)+EMFDGL(I))
    1 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RURAL
      COMMON /RURALB/ YLD(2),OPUT(3),A1(2),NT,RNUTPR,RBR,PDTHR,PDTHR1,
     +                RDTHSM,RDR,XFR1,FR1,PCONSR,CONSF,FR3,RSTORD,
     +                RD2,PR,TRDTHM,RNUTDP,PFDFN,RH1,RH2,PANUTD,
     +                NTSH(2),R1(20),R2(10),PANTDP,EMFSU,RNTDP1,FR2,
     +                ERSTOR,ERNTDP
      COMMON /BLOCK/ DUF,DT,DETPRT,SELPRT,BEGPRT,PRTCHG,PRTVL1,PRTVL2,
     1               G1,GSTKD,GNSLS,CG1,CG2,CG3,TPUND0,CG5,TPUND1,GSU1
     2              ,GSRD,GSUD,GCONMX,GDE,WF,RK1,RK2,RDE,CM1,CG7,CGP,
     3               CG20,CG21,CG22,CG23,CG24,CG25,CG26,CG27,CG28,
     +               CG29,CG30,CG31,CG32,CG33,CG34,CIG1,PRIPOP,PRGPC,
     +               TSEA,DFLINF,CG35,CG36,SDND,SDRC,DELD,DELRC,SAMPT,
     +               BIASL,BIASRC,VARTME,MONPR,SMPRC,SMPUS,DELUS,SDUS,
     +               BIASUS,SMPRS,DELRS,BIASRS,SDRS,CG60,CG61,CRUT,
     +               CG70,CG71,CG72,CG73,CG74,CG75,CG76,CG77
      COMMON /GOVTB/  GIMFD,GSRU,EMFDG,TANUTG,GCONRP,GPSTK,GSR,GSU,
     +                GIMF,GFRRU,GBAL,GCONF,GIMPMX,TPUND,CG4,CG6,
     +                CHI,ER,FWLI,RSTORM,FATWT,UFWT,AEUNDP,AERCNU,
     +                RDBJ,UDBJ,ERCNTU(3),ERCNTR,GSLSDU,GFSTRD
     +         ,EPCONR,EPCONU(3),EIMP,EPU(3),GUSTRD(3),ERNUT(3),ERNUTR,
     +          ECHIEF
      COMMON /SYSVAR/ ANUTDP(3),RSTOR,PFD,PFDR,T,MIGIN(3),MIGOUT(3),
     +                UPUF(3),EMFD(3),DPFRDT,RSUP,RSALES,EMFDGU(3),
     +                GSLS,GSLSD,UDEM(3),DPFDDT,PU(3),ARNUT,EDPC,
     +               EDPCS,EMEFG,ESTGDF,ETDSTG,ETPOP,TPOP,TTSH,EMFINT
     +              ,RNUTPN,RCNTR,EMFDGL(3),RCNTU(3)
      REAL MIGIN,MIGOUT
      DIMENSION ALND(2),VALD(6),VALFR1(5),VALFR3(4),YLDN(2)
      DATA ALND(1),ALND(2)/1.23 E+06 ,1.3 E+06 /
      DATA YLDN(1),YLDN(2)/3.3   ,2.2 /
      DATA UK4,UK5,RNUTPN/2.92 ,-.182 ,.228/
      DATA  B1,B2 /.04,1./
      DATA VALD(1),VALD(2),VALD(3),VALD(4),VALD(5),VALD(6)/0.,.05,.25,
     1.5,.85,1.0/
      DATA DR0/.02/
      DATA (VALFR1(J1),J1=1,5) /0.,.4,.85,.98,1.0/
      DATA RK6/30./
      DATA (VALFR3(J),J=1,4) /9.,1.,.9,.8/
      DATA RSTINC /0./
      IF (T.GT.DT) GO TO 9
      RNTDPM=0.
      RNDPM1 = .1E-10
      RSALES=0.
      RSTORD=.194E+07
      EMFSL = 0.
      EMFD(1) = 0.
      EMFD(3) = 0.
      FR2A=2.5
      DO 65 I=1,2
      YLD(I)=YLDN(I)*WF
      OPUT(I)=YLD(I)*ALND(I)
   65 CONTINUE
      NMAX=1./DT+.0001
    9 CONTINUE
      DO 66 I=1,2
      A1(I)=0.
   66 IF (NT.EQ.NTSH(I)) A1(I)=OPUT(I)/DT
      NT=NT+1
      IF (NT.EQ.NMAX) NT=1
      RNUTPR=AMAX1((RNUTPN-UK4*RNUTDP),UK5)
      RBR=AMIN1(AMAX1((B1*(1.+B2*((PCONSF-RNUTPR)/RNUTPR))),0.),B1)*PF
      RNTDPM=AMAX1(RNTDPM,RNUTDP)
      PDTHR=TABLIE(VALD,0.,.01,5,RNTDPM)
      PDTHR1=TABLIE(VALD,0.,.01,5,RNTDP1)
      PDTHR1=TABLIE(VALD,0.,.01,5,RNDPM1)
      RNDPM1=RNTDPM
      RNTDP1=RNUTDP
      RDTHSM=AMAX1((PDTHR-PDTHR1)*(PP+TRDTHM),0.)
      RDR=RDTHSM/DT+DR0*PF
```

```
C           COMPUTE RURAL PER CAP CONS--PCONSR
C                COMPUTE TOTAL TIME TO START OF NEAREST HARVEST
      IF (NT.LE.NTSH(2)) TTSH=NTSH(2)-NT
      IF (NT.GT.NTSH(2).AND.NT.LE.NTSH(1)) TTSH=NTSH(1)-NT
      IF (NT.GT.NTSH(1)) TTSH = NMAX-NT+NTSH(2)
      TTSH=TTSH*DT
C
C                                  COMPUTE TIME OF DESIRED STORAGE
      TDSTO = 1.8 - 1.15*T
      IF(T.LE..9) TDSTO = -3.64 + 4.88*T
      IF(T.LE..77) TDSTO = .9-T
      IF(T.LE..7 ) TDSTO = .32
      IF(T.LE..55) TDSTO = .65 - 1.15*T
C
C                                  COMPUTE DESIRED CONSUMPTION WEIGHTING FACTORS
      XFR1 = RSTOR / ((RNUTPR*PR+EMFSL) * TDSTO)
      FR1 = AMIN1(XFR1,1.0)
C                  COMPUTE PERCEIVED NUTRIONAL DEBT-PANUTD--MT/PERSON
      PANUTD=PANUTD+(DT/.25)*(FDE*ANUTDP(2)-PANUTD)
      PURND=(PANUTD-PANTDP)/DT
      PANTDP=PANUTD
C
C           COMPUTE EMER FD SENT TO URBAN AREA-EMFSU=EMFD
      EMFSU=AMAX1((FR1*(RK1*(PANUTD-RNUTDP)+RK2*PURND)*PU(2)),0.)
      IF(RSTOR.LT..2E5) EMFSU = 0.0
      EMFSL = EMFSL + (DT/.05)*(EMFSU-EMFSL)
      EMFD(2) = EMFSL
C
C                                  COMPUTE PER-CAPITA CONSUMPTION
      PCONSR = AMIN1( .4, XFR1*RNUTPN, FR1*(RNUTPR+RK6*RNUTDP) )
      IF(RSTOR.LT..5 ) PCONSR = 0.0
      CONSR=PCONSR*PR
C           COMPUTE RURAL FD  OFFERED FOR SALE-RSUP
C                COMPUTE RURAL FOOD STORAGE DESIRED
      PRATIO=PFDR/PFDRN
      FR3=TABLIE(VALFR3,0.,1.,3 ,PRATIO)
      RSTDU = ((RNUTPR+1.9*PNUTDP)*PR+EMFSU) * FR3 * TDSTO
      RSTORD=RSTORD+(DT/.03)*(RSTDU-RSTORD)
      FR2=AMAX1((2.5-.5*DFFRDT/PFDR),1.)
      FR2A=FR2A+(DT/.05)*(FR2-FR2A)
      FR2=AMIN1(FR2A,2.5)
      FR2A=AMIN1(FR2A,2.5)
      RSUP=AMAX1(FR2*(RSTOR-RSTORD),0.)  +1.E-06
      IF(RSTOR.LT..2E5) RSUP  = 0.0
      RCNTR = RNUTPR-PCONSR
C           COMPUTE STATE VARIABLES
      PR = PR + DT*(RBR - RDR + MIGOUT(1) + MIGOUT(2) + MIGOUT(3) -
     1     MIGIN(1) - MIGIN(2) - MIGIN(3))
      TRDTHM=TRDTHM+RDTHSM
      RNUTDP=RNUTDP+DT*(RNUTPR-PCONSR)
      RSTOR=RSTOR+DT*(RH1+RH2-RSALES-CONSR-EMFSU-GCONF)
      CALL DELDT(A1(1),RH1,R1,.07,5 ,DT,10)
      CALL DELDT(A1(2),RH2,R2,.07,5 ,DT,10)
      RETURN
      END
```

```
      SUBROUTINE GOVT
      COMMON /GOVTB/  GIMPO,GSRU,EMFDG,TANUTD,GCONRF,GPSTK,GSF,GSU,
     +                GIMP,GFRRU,GBAL,GCONR,GIMPMX,TPUND,CG4,CG6,
     +                CHI,ER,PWLD,RSTORM,FATWT,URWT,AEUNDP,AERCNU,
     +                ROBJ,UOBJ,ERCNTU(3),ERCNTR,GSLSDU,GRSTRD
     +        ,EPCONR,EPCONU(3),EIMP,EPU(3),GUSTRD(3),ERNUT(3),ERNUTR,
     +        ECHARF
      COMMON /BLOCK/ DUR,DT,DETPFT,SELPFT,REGPRT,FRTCHG,PRTVL1,PRTVL2,
     1               G1,GSTKD,GNSLS,CG1,CG2,CG3,TPUNDO,CG5,TFUND1,GSU1
     2              ,GSRD,GSUD,GCONMX,GDE,WF,RK1,RK2,RDE,CM1,CG7,CGP,
     3               CG20,CG21,CG22,CG23,CG24,CG25,CG26,CG27,CG28,
     +               CG29,CG30,CG31,CG32,CG33,CG34,CIG1,PRIPOP,PRGPC,
     +               TSEA,DELINF,CG35,CG36,SDRD,SDRC,DELD,DELRC,SAMPT,
     +               BIASD,BIASRC,VARTME,MONFP,SMFRC,SMPUS,DELUS,SDUS,
     +               BIASUS,SMPRS,DELRS,BIASRS,SDRS,CG60,CG61,CRUT,
     +               CG70,CG71,CG72,CG73,CG74,CG75,CG76,CG77
      COMMON /SYSVAR/ ANUTDP(3),RSTOR,PFD,PFDR,T,MIGIN(3),MIGOUT(3),
     +                UPUP(3),EMFD(3),DPFRDT,RSUP,RSALES,EMFDGU(3),
     +                GSLS,GSLSD,UDEM(3),DPFDDT,PU(3),ARNUT,FDPC,
     +               EDPCS,EMERG,ESTGDF,ETDSTG,ETPOP,TFOF,TTSH,EMFINT
     +              ,RNUTPN,RCNTR,EMFDGL(3),RCNTU(3)
      REAL MIGIN,MIGOUT
      COMMON /RURALB/ YLD(2),OPUT(3),A1(2),NT,RNUTPR,RER,RDTHR,PDTHR1,
     +                RDTHSM,RDR,XFR1,FR1,PCONSR,CONSR,FF3,RSTORD,
     +                PD2,PR,TRDTHM,RNUTDP,PFDRN,RH1,RH2,RANUTD,
     +                NTSH(2),R1(20),R2(10),PANTDP,EMFSU,RNTDP1,FR2,
     +                EFSTOP,ERNTDP
      COMMON /URBANB/ RNUTP(3),BR(3),PDTH(3),PDTHM1(3),ANTDP1(3),
     +                DTHSM(3),XFU1(3),FU1(3),PCONSU(3),CONSU(3),
     +                USTORD(3),DEMP(3),AINC(3),TDTHSM(3),USTOR(3),
     +                EUSTOP(3),EATNDP(3)
      COMMON /COSTSB/ GCON,EMFTOT,GSLTOT,EMTRAN,EMSTOR,GIMTOT,CGSLS,
     2                CGCON,CEMFD,CPROG,CGSRU,CSTOR,CGIMP,COSTGP,CDELD,
     3                 CSURN,CSURCU,CSURFL,CYRSUR,SNUMNT,SNUMCT,SNUMS,
     4                 SNUMN(4),SNUMC(4),COSTGX,COSTOT
      DIMENSION RI(3),RTRU(3)
      DIMENSION UDA1(50),UDA2(50),UDA3(50),RDA(50),UCA1(50),UCA2(50),
     +          UCA3(50),RCA(50),RSA(50)
      DIMENSION ECPUT(2)
      DIMENSION VALGS(6)
      DATA CG8/ 0. /
      DATA PFDD /.115E+06/
      DATA CG50 /.15/
      DATA GFREV /160.E+09/
      DATA SFHT,SFRPS / .15, .15 /
      DATA SFGCN,SOFRCT / .10,.20 /
      DATA UK4,UK5 / 2.92, .182 /
      DATA GSUM / .155 /
      DATA VALGS / .02,.15,.25,.15,.5,.76 /
C                                                 INITIALIZATION PHASE
      IF (T.GT.DT) GO TO 4
      DO 5 II=1,3
      EUSTOR(II) = 60000.
      EATNDP(II) = .1E-10
      EPCONU(II) = RNUTPN
      RI(II) = .1E7
      EPU(II) = 6000000.
       EMFDGL(II)=0.
    5 RTRU(II) = .1E7
      ETPOP = 34000000.
      EPR = 16000000.
      EDPCS = .02
      EATNDP(3) = -.01
      ERNTDP = .1E-10
      EPCONR = RNUTPN
      ETHA2 = .57
      YRENDH = .9
C                  INITIAL VALUES FOR INFORMATION DELAY ARRAYS
      EUD1 = EATNDP(1)
      EUD2 = EATNDP(2)
      EUD3 = EATNDP(3)
      ERD = ERNTDP
      EUC1 = EPCONU(1)
      EUC2 = EPCONU(2)
      EUC3 = EPCONU(3)
      ERC = EPCONR
      ERS = ERSTOR
```

```
C                             CROP YIELD AND HARVEST ESTIMATES
      ECPFAC = 1.
      EOPUT(1) = OPUT(1)*ECPFAC
      EOPUT(2) = OPUT(2)*ECPFAC
      ERH1 = 0.0
      ERH2 = 0.0
      ECHARF = 0.0
C                          INITIALIZE STATES AND OTHERS
      GSLSD = 2000000.
      GSLS=0.
      GFRPU = .1E7
      GSPL  = .1E7
      GIMPO = .1E7
      GIMP  = .1E7
      EIMP  = .1E7
      TFUND=0.
      GCONR=0.
      GCON = 0.0
      EMFTOT = 0.0
      GSLTOT = 0.0
      EMTRAN = 0.0
      EMSTOR = 0.0
      GIMTOT = 0.0
      CGELS = 0.0
      GP = 0.0
      REMFDG = 0.0
      GSRUMX = 1.5*GNSLS
      GSW = (GSRD+GSUD)*CG60
      DELRC = 0.0
C
C                                                   BEGIN EXECUTION PHASE
    4 CONTINUE
C
C                                ***** DATA COLLECTION PROCESSES
C
C                             ESTIMATE POPULATION SIZE
      RANDO = RANF(-1)
      DO 20 J=1,3
      EPU(J) = EPU(J) + ((1.+CG23*(RANDO-.5)) *PU(J) -EPU(J)) * DT/CG22
   20 CONTINUE
      EPR = EPR+((1.+CG23*(RANDO-.5)) *PR - EPR) * DT/CG22
      EUPOP = EPU(1) + EPU(2) + EPU(3)
      TPOP = PR + PU(1) + PU(2) + PU(3)
      ETPOP = EPR + EUPOP
C
C                             ESTIMATE GOVERNMENT GRAIN IMPORT RATE
      EIMP = EIMP + (DT/CG50) * (GIMPO-EIMP)
C
C
C                             ESTIMATE HARVESTING RATE AND
                              CURRENT HARVEST STILL IN FIELDS
      ERH1 = ERH1 + (DT/.02)*(RH1-ERH1)
      ERH2 = ERH2 + (DT/.02)*(RH2-ERH2)
      IF(NT.EQ.NTSH(2)) ECHARF = ECHARF + EOPUT(2)
      IF(NT.EQ.NTSH(1)) ECHARF = ECHARF + EOPUT(1)
      ECHARF = ECHARF - DT*(ERH1+ERH2)
   36 ECHARF = AMAX1(ECHARF,0.0)
C
C                             SAMPL SIMULATES MEASUREMENT ERROR
C                             NUTRITIONAL DEBT, PER-CAPITA CONSUMPTION,
C                             PRIVATE STORAGE
C
      CALL SAMPL(ANUTDP(1),EATNDP(1),UDA1,EUD1,SAMPT,DELD,BIASD,SDND,1,
     2           DT,T,CG28,CG29)
      CALL SAMPL(ANUTDP(2),EATNDP(2),UDA2,EUD2,SAMPT,DELD,BIASD,SDND,2,
     2           DT,T,CG28,CG29)
      CALL SAMPL(ANUTDP(3),EATNDP(3),UDA3,EUD3,SAMPT,DELD,BIASD,SDND,3,
     2           DT,T,CG28,CG29)
      CALL SAMPL(RNUTDP,ERNTDP,RDA,ERD,SAMPT,DELD,BIASD,SDND,4,
     2           DT,T,CG28,CG29)
      CALL SAMPL(PCONSU(1),EPCONU(1),UCA1,EUC1,SMPRC,DELD,BIASD,SDRC,5,
     2           DT,T,CG28,CG29)
      CALL SAMPL(PCONSU(2),EPCONU(2),UCA2,EUC2,SMPRC,DELD,BIASD,SDRC,6,
     2           DT,T,CG28,CG29)
      CALL SAMPL(PCONSU(3),EPCONU(3),UCA3,EUC3,SMPRC,DELD,BIASD,SDRC,7,
     2           DT,T,CG28,CG29)
      CALL SAMPL(PCONSR,EPCONR,RCA,ERC,SMPRC,DELD,BIASD,SDRC,8,
     2           DT,T,CG28,CG29)
      CALL SAMPL(RSTOR,ERSTOR,RSA,ERS,SMPRS,DELD ,BIASRS,SDRS,12,
     2           DT,T,CG28,CG29)
```

```
C
C
C
C                          *****  CALCULATE NEEDED INFORMATION VALUES
C
C                              COMPUTE DESIRED STORAGE TIMES
      GTDSTO = .65-1.105*T
      IF(T.GT.ETHA2) GTDSTO = TABLIE(VALGS,.57,.165,5,T)
      IF(T.GT.YRENDH) GTDSTO = 1.75-1.105*T
C
C                         ESTIMATE STORAGE DEFICIT PER CAPITA
      ETDSTG = (GTDSTO+.05)*ETPOP*(RNUTPN-EIMP/ETPOP)
      ETSTG = GSL + GSF + ERSTOR
      ESTGDF = ETDSTG - ETSTG
      EDPC = ESTGDF/ETPOP
      EDPCS = EDPCS + (EDPC - EDPCS)*DT/CG20
C
C                              CURRENT REQUIRED NUTRITION AND
C                              RATE OF CHANGE OF NUTRITIONAL DEBT
      DO 221 J=1,3
      ERNUT(J) = AMAX1( RNUTPN-UK4*EATNDP(J) , UK5)
      ERCNTU(J) = ERNUT(J) - EPCONU(J)
  221 CONTINUE
      ERNUTR = AMAX1( RNUTPN-UK4*FRNTDP, UK5 )
      ERCNTR = ERNUTR-EPCONR
C
C                              AVAILABLE NUTRIENTS AND DESIRED STORAGE
      ARNUT = AMIN1( (EIMP+ETSTG/GTDSTO)/ETPOP, RNUTPN )
      GRSTRD = EPR*ARNUT*GTDSTO
      DO 220 J=1,3
      GUSTRD(J) = CG33*RNUTPN*EPU(J)
  220 CONTINUE
C
C                              CALCULATE URBAN AVERAGES
      AERCNU = 0.
      AEUPCN = 0.0
      AEUNDP=0.
      DO 891 J =1,3
      AERCNU = AERCNU + ERCNTU(J)*EPU(J)
      AEUPCN = AEUPCN + EPCONU(J)*EPU(J)
  891 AEUNDP = AEUNDP + EATNDP(J)*EPU(J)
      TUCGND = AERCNU
      TPUND = AEUNDP
      AERCNU = AERCNU/EUPOP
      AEUPCN = AEUPCN/EUPOP
      AEUNDP = AEUNDP/EUPOP
C
C                              *****  DECISION RULES BASED ON AVAILABLE
C                              *****  INFORMATION AND PREDETERMINED POLICIES
C
C                              GOVERNMENT IMPORT ORDERS
      IF(GBAL.LT.0.) GO TO 1
      GSTK=GSR+GSU
      GIMPO=AMIN1(AMAX1(G1*(GSTKD-GSTK-GPSTK)+GNSLS,0.),GIMPMX)
      GO TO 2
    1 GIMPO=0.
C
C                              RURAL TO URBAN SHIPPING RATE
    2 GSRU = AMIN1( AMAX1( CG1*(GSR-GSRD), 0.0 ), GSRUMX )
      IF(GSU.LT.GSUD) GSRU =
     2          AMIN1(AMAX1(CG1*CG25*(GSR-GSRD),0.0),GSRUMX)
C
C                              DECLARATION OF EMERGENCY - TIMING TRIGGER
      EMERG = 0.
      IF(EDPCS .GE. CG21) EMERG = 1.
      IF(EMERG .NE. 0.) GO TO 200
C
C                              PRICE CONTROL POLICY
C
      GSLSDU = AMAX1(CG8*TPUND, 0.0) + CGP*(PFD-PFDD)/PFDD + GNSLS
      IF(GSU.LT.GSUM) GSLSDU = 1.E-6
      GSLSDU = AMAX1(GSLSDU,1.E-6)
      GSLSDU = AMIN1(GSLSDU,6.E+6)
      EMFDGT = AMAX1( (CG3*GSU*(TPUND-TPUNDO)/TPUNDO)
     2              +CG7*AMAX1(TUCGND,0.),0.)
      IF(GSU.LT.GSUM) EMFDGT = 1.E-6
      EMFDGU(3) = 0.0
      EMFDGU(2) = EATNDP(2)/(EATNDP(1)+EATNDP(2)) * EMFDGT
      EMFDGU(1) = EMFDGT-EMFDGU(2)
      GCONRP=AMIN1(AMAX1((CG5*(TPUND-TPUND1)),0.),GCONMX)
      IF (GSL.GT.250000.) GCONRP=0.
      IF(ERSTOR.LT.RSTORM) GCONRP=0.
      GO TO 300
```

```
C
C
C                         EMERGENCY ACQUISITIONS AND RATIONING POLICIES
  200 CONTINUE
      DELRC = DELRC + DT
      GCONRP = CG30 * AMAX1(ERSTOR - GRSTRD, 0.0)
     2          + CG36*(AEUNDP-ER TDP)*EPR
     3          + CG35 * (EPCONR-AEUPCN) *EPR
      IF(GSR.GT.GSRD) GCONRP = AMIN1(GCONRP,GSRUMY-EIMP)
      IF(AEUNDP.LT.0.0) GCONRP = AMAX1(DELUS*(ERSTOR-GRSTRD),0.0)
   45 CONTINUE
      IF(EPCONR.LT.UK5) GCONRP = 0.0
      GCONRP = AMAX1(GCONRP,0.)
      IF(ERSTOR.LT.RSTORM) GCONRP=0.
C
      GSLSDU = DELRS*ARNUT*(EPU(3)+CG31*(EPU(1)+EPU(2)))
     2          + CG32 * (EATNDP(3)-(EATNDP(1)+EATNDP(2))/2.) * EPU(3)
     3          + CG34 * (GUSTRD(3)-EUSTOR(3))
     4          + GDE*((EPCONU(1)+EPCONU(2))/2. - EPCONU(3)) * EPU(3)
      IF(EATNDP(3).LT.0.0) GSLSDU =
     2       DELRS*ARNUT*(EPU(3) + CG31*(EPU(1)+EPU(2)))
     3       + (CG32*CG2) * (EATNDP(3)-(EATNDP(1)+EATNDP(2))/2.)*EPU(3)
     4       + CG34 * (GUSTRD(3) - EUSTOR(3))
     5       + GDE * ((EPCONU(1)+EPCONU(2))/2. - EPCONU(3))*EPU(3)
      GSLSDU = AMAX1(GSLSDU,ARNUT*.75 *EPU(3))
      IF(GSU.LT.GSUM) GSLSDU = 0.0
C
      DO 240 J=1,2
      EMFDGU(J) = DELRS*ARNUT*EPU(J)
     2       + CG27*(EATNDP(J) - (EATNDP(1)+EATNDP(2))/2.)*EPU(J)
     3       + CG34 * (GUSTRD(J)-EUSTOR(J))
     4       +CG24*((EPCONU(1)+EPCONU(2))/2. - EPCONU(J)) * EPU(J)
      IF(GSU.LT.GSUM) EMFDGU(J) = 0.0
      EMFDGU(J) = AMAX1(EMFDGU(J),0.0)
  240 CONTINUE
      EMFDGU(3) = 0.
  300 CONTINUE
C
C                         IMPLEMENTATION DELAYS - RATE VARIABLES
      GCONR=GCONR+(DT/CG6)*(GCONRP-GCONR)
      IF(RSTOR.LT..5E3) GCONR = 0.0
      GSLSD = GSLSD + (GSLSDU - GSLSD)*DT/.05
      IF(GSU.LT..5E3) GSLSD = 0.0
      EMFDG = 0.0
      DO 241 J=1,3
      EMFDGL(J)=EMFDGL(J) +(DT/.05)*(EMFDGU(J)-EMFDGL(J))
      IF(GSU.LT..5E3) EMFDGL(J) = 0.0
      EMFDG=EMFDG+EMFDGL(J)
  241 CONTINUE
C
C                         *****  COMPUTE STATE VARIABLES
C
      GPSTK=GPSTK+DT*(GIMPO-GIMP)
      GSR=GSR+DT*(GIMP+GP+EMFINT+GCONR-REMFDG-GSRU)
      GSU=GSU+DT*(GFRRU-GSLS-EMFDG)
      GBAL=GBAL+DT*(GSLS*PFD+GFREV-GIMPO*PWLD*ER-CHI*(GSR+GSU)-GP*PFDR)
      TANUTD=0.
      DO 3 J=1,3
    3 TANUTD=TANUTD+ANUTDP(J)*PU(J)
C
C                         TRANSPORTATION DISTRIBUTED DELAYS
      CALL DELDT(GIMPO,GIMP,RI,.15  ,1   ,DT,3 )
      CALL DELDT(GSRU,GFRRU,RTPU,.03,2 ,DT,3)
C
C                         EMERGENCY OPERATION QUANTITIES
      GCON = GCON + DT*GCONR
      EMFTOT = EMFTOT + DT*EMFDG
      GSLTOT = GSLTOT + DT*GSLS
      EMTRAN = EMTRAN + DT*(GSRU-GNSLS)
      EMSTOR = EMSTOR + DT*(GSR+GSU-GSN)
      GIMTOT = GIMTOT + DT*GIMP
      CGSLS = CGSLS + DT*PFD*GSLS
      RETURN
      END
```

```
      SUBROUTINE MKT
      COMMON /MKTB/   DEM,SUP
      COMMON /BLOCK/ DUR,DT,DETPRT,SELPRT,BEGPRT,PRTCHG,PRTVL1,PRTVL2,
     1               G1,GSTKD,GNSLS,CG1,CG2,CG3,TPUND0,CG5,TPUND1,GSU1
     2              ,GSRD,GSUD,GCONMX,GDE,EF,FK1,FK2,RDE,CM1,CG7,CGP,
     3               CG20,CG21,CG22,CG23,CG24,CG25,CG26,CG27,CG28,
     +               CG29,CG30,CG31,CG32,CG33,CG34,CIG1,PRIPDP,PRGPC,
     +               TSEA,DELINF,CG35,CG36,SDMD,SDRC,DELD,DELRC,SAMPT,
     +               BIASD,BIASRC,VARTME,MONPP,SMPRC,SMPUS,DELUS,SDUS,
     +               BIASUS,SMPRS,DELRS,BIASRS,SDRS,CG60,CG61,CRUT,
     +               CG70,CG71,CG72,CG73,CG74,CG75,CG76,CG77
      COMMON /SYSVAR/ ANUTDP(3),FSTOR,PFD,PFDR,T,MIGIN(3),MIGOUT(3),
     +                UPUR(3),EMFD(3),DPFRDT,RSUP,RSALES,EMFDGU(3),
     +                GSLS,GSLSD,UDEM(3),DPFDDT,PU(3),ARNUT,EDPC,
     +               EDPCS,EMERG,ESTGDF,ETDSTG,ETPOP,TPOP,TTSF,EMFINT
     +              ,ANUTPN,RCMTR,EMFDGL(3),RCNTU(3)
      REAL MIGIN,MIGOUT
      DATA DEMO /3.6E+06 /
      DATA CM2 /.85/
C           COMPUTE RATE VARIABLES
      DEM=UDEM(1)+UDEM(2)+UDEM(3)
      SUP=GSLSD+FSUP
      DPFDDT =CM2*((DEM-SUP)/DEMO)*PFD
      DPFDDT=AMIN1(DPFDDT,3.E06)
      IF(DEM.LT.SUP) GO TO 1
C           DEM GE SUP
      GSLS=GSLSD
      RSALES=RSUP
      UPUR(3)=AMIN1(SUP,UDEM(3))
      UPUR(1)=UDEM(1)*(SUP-UPUR(3))/(UDEM(1)+UDEM(2)+.001)
      UPUR(2)=SUP-UPUR(3)-UPUR(1)
      GO TO 2
C           DEM LT SUP
    1 DO 3 II=1,3
    3 UPUR(II)=UDEM(II)
      RSALES=DEM*RSUP/(RSUP+GSLSD)
      GSLS=DEM-RSALES
    2 CONTINUE
      DPFDDT=CM2*DPFDDT
C           COMPUTE STATE VARIABLES
      PFD=PFD+DT*DPFDDT
      PFD = AMIN1(PFD,VARTME )
      PFDR=PFD*CM2
      RETURN
      END
```

```
      SUBROUTINE VARCAL
      COMMON /VAR/ NXNS,XBARM(10),VARXM(10),XNM(10),NVARV
      REAL N
      N = FLOAT(NXNS)
      ENVERS = 1./N
      DO 1 I=1,NVARV
      VARXM(I) = VARXM(I)*(N-2.)/(N-1.)+ENVERS*(XBARM(I)-XNM(I))
     2          *(XBARM(I)-XNM(I))
      XBARM(I) = ENVERS*(XBARM(I)*(N-1) + XNM(I))
    1 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SAMPL(VAL,VALEST,VALAR,ENIT,SAMPT,DEL,BIAS,SD,NK,
     2              DT,T,ALPHA,BETA)
C                   VAL = ACTUAL VALUE,       VALEST = ESTIMATE OF VAL
C                   VALAR = ARRAY OF INFO IN DELAY PIPELINE
C                   ENIT = INITIAL ESTIMATED VALUE,   DEL = DELAY LENGTH
C                   SAMPT = SAMPLING INTERVAL(YR),  BIAS = MEASUREMENT BI
C                   SD = MEASUREMENT STANDARD DEVIATION
C                   NK = COUNTER, NUMBER OF ITEM MEASURED
      DIMENSION HOLD(12),NCNT(12),NSAMP(12),NN(12),VALAR(1),NMLVAL(41)
      DIMENSION YP(12),YY(12),YD(12)
      REAL NMLVAL
      DATA N /50/
      DATA NMLVAL  / -3.5, -1.96, -1.645, -1.439, -1.281, -1.150,
     2         -1.037, -.925, -.841, -.755, -.674, -.598, -.524,
     3         -.454,-.386, -.312, -.253, -.189, -.126, -.056, 0.0,
     4         .056, .126, .189, .253, .312, .386, .454, .524, .598,
     5         .674, .755, .841, .925, 1.037, 1.150, 1.281, 1.439,
     6         1.645, 1.960, 3.500  /
      IF(T.GT.DT+.00001) GO TO 20
C                          INITIALIZATION OF ARRAY AND COUNTERS
      DO 21 KK=1,N
   21 VALAR(KK) = ENIT
C                   HOLD = MEASURED VALUE HELD UNTIL NEXT SAMPLE TIME
C                   NCNT = NUMBER OF DTS SINCE LAST SAMPLING
C                   NSAMP = NUMBER OF DTS BETWEEN SAMPLINGS
C                   NN = NUMBER OF DTS DELAY LASTS
      HOLD(NK) = 0.0
      NCNT(NK) = 0
      NSAMP(NK) = 0
      NN(NK) = DEL/DT+.5
      YY(NK) = ENIT
      YD(NK) = 0.0
      ALPHA = 2*SQRT(BETA) - BETA
C                          EXECUTION PHASE
   20 NCNT(NK) = NCNT(NK)+1
      IF(NCNT(NK).LT.NSAMP(NK)) GO TO 1
C                          SAMPLING PROCEDURE
C                          Y IS STANDARD NORMAL RANDOM VARIABLE
      NSAMP(NK) = SAMPT/DT+.5
      R = RANF(-1)
      Y = TABLIE(NMLVAL,0.,.025,40,R)
      HOLD(NK) = VAL*(1.+SD*Y) + BIAS
C                   FOR NUTRITIONAL DEBT ESTIMATES, USE FIXED STANDARD
C                   DEVIATIONS
      IF(NK.LE.4) HOLD(NK) = VAL + SD*Y + BIAS
      YP(NK) = YY(NK) + SAMPT*YD(NK)
      YY(NK) = YP(NK) + ALPHA*(HOLD(NK)-YP(NK))
      YD(NK) = YD(NK) + (BETA/SAMPT) * (HOLD(NK)-YP(NK))
      NCNT(NK) = 0
    1 CONTINUE
      CALL VITDLI(YY(NK),VALEST,VALAR,N,NN(NK),DEL,DT)
      RETURN
      END
       FUNCTION TABLIE(VAL,SMALL,DIFF,K,DUMMY)
       DIMENSION VAL(1)
       DUM = AMIN1(AMAX1(DUMMY-SMALL,0.0),FLOAT(K)*DIFF)
       I = 1.0 + DUM/DIFF
       IF( I .EG. K+1) I = K
       TABLIE = (VAL(I+1)-VAL(I))*(DUM-FLOAT(I-1)*
     +DIFF)/DIFF+VAL(I)
       RETURN
       END
       SUBROUTINE DELDT(RINR,ROUTR,CROUTR,DEL,IDT,DT,K)
       DIMENSION CROUTR(1)
       DEL1 = DEL*FLOAT(IDT)/(FLOAT(K)*DT)
       ROUTR = 0.0
       DO 2 J = 1,IDT
       RIN = RINR/FLOAT(IDT)
       DO 1 I = 1,K
       ABC = CROUTR(I)
       CROUTR(I) = ABC + (RIN-ABC)/DEL1
    1  RI. = ABC
    2  ROUTR = ROUTR + CROUTR(K)
       RETURN
       END
```

```
      SUBROUTINE NAMLST(NAMVAR, NVAR, ERROR)
      INTEGER BLANK,DOLLAR
      DIMENSION DUMMY(1),IDUMMY(1),NAMVAR(1)
      DIMENSION INT(4),LAST(4),NAME(4),VALUE(4)
      COMMON /BLOCK/ DUMMY
      EGUIVALENCE (DUMMY(1),IDUMMY(1))
      DATA BLANK,DOLLAR / 1H , 1H$ /
      ERROR=0.
10    READ(1,900) (NAME(I),INT(I),VALUE(I),LAST(I),I=1,4)
      IF(EOF(1).NE.0.)RETURN
      DO 50 I=1,4
      IF(NAME(I).EG.BLANK)GO TO 45
      DO 30 J=1,NVAR
      IF(NAME(I).EG.NAMVAR(J))GO TO 35
30    CONTINUE
      WRITE(2,901) NAME(I)
      ERROR = 1.
      RETURN
35    WRITE(2,902) NAME(I),VALUE(I)
      IF(INT(I).NE.BLANK)GO TO 40
      DUMMY(J) = VALUE(I)
      GO TO 45
40    IDUMMY(J) = VALUE(I)
45    IF(LAST(I).EG.DOLLAR)RETURN
50    CONTINUE
      GO TO 10
900   FORMAT(4(A6,1X,A1,E9.4,A1))
901   FORMAT(24H0**ERROR** VARIABLE NAME,A7,10H NOT FOUND)
902   FORMAT(1H0,A6,3H = ,E12.4)
      END


      SUBROUTINE VDTDLI(VIN,VOUT,VINT,N,NN,DEL,DT)
C                          VIN = INPUT VALUE,     VOUT = OUTPUT VALUE,
C                          VINT = ARFAY (TRAIN),     N = MAX SIZE OF TRAIN
C                          DT = TIME INCREMENT,    DEL = CURRENT DELAY REPRE
C                          NN = SIZE OF TRAIN AT TIME (T-DT)
      DIMENSION VINT(1)
      NNNEW = DEL/DT+.5
      IF(NNNEW.LT.2) NNNEW=2
      IF(NNNEW.GT.N) NNNEW=N
      VOUT = VINT(1)
      NDIF = NNNEW-NN
    1 IF(NDIF.LE.0) GO TO 4
C                          DEL INCREASES, RECENT DATA HELD LONGER
      DO 3 II=1,NDIF
    3 VINT(II+NN) = VINT(NN)
    4 CONTINUE
C                          DEL UNCHANGED, CURRENT DATA KEPT
C                          DEL SHRINKS, OLDEST DATA SAVED
      NN = NNNEW
      DO 6 I=2,NN
    6 VINT(I-1) = VINT(I)
      VINT(NN) = VIN
      RETURN
      END
```

```
      SUBROUTINE COSTS
      COMMON /BLOCK/ DUR,DT,DETPPT,SELPPT,BEGPRT,PRTCHG,PRTVL1,PRTVL2,
     1               G1,GSTKD,GNSLS,CG1,CG2,CG3,TPUND0,CG5,TFUND1,GSU1
     2              ,GSRD,GSUD,GCONMX,GDE,WF,RK1,RK2,RDE,CM1,CG7,CGP,
     3               CG20,CG21,CG22,CG23,CG24,CG25,CG26,CG27,CG28,
     +               CG29,CG30,CG31,CG32,CG33,CG34,CIG1,PPIPOP,PRGPC,
     +               TSEA,DELINF,CG35,CG36,SDND,SDRC,DELD,DELRC,SAMPT,
     +               EIASD,EIASRC,VARTME,MONPR,SMPRC,SMPUS,DELUS,SDUS,
     +               EIASUS,SMPRS,DELRS,EIASRS,SDRS,CG60,CG61,CRUT,
     +               CG70,CG71,CG72,CG73,CG74,CG75,CG76,CG77
      COMMON /COSTSB/ GCON,EMFTOT,GSLTOT,EMTRAN,EMSTOR,GIMTOT,CGSLS,
     2                CGCON,CEMFD,CPROG,CGSRU,CSTOR,CGIMP,COSTGP,CDELD,
     3                 CSURN,CSURCU,CSURFU,CYRSUR,SNUMNT,SNUMCT,SNUMS,
     4                 SNUMN(4),SNUMC(4),COSTGX,COSTOT
      DIMENSION WH(4),SHN(4),SHC(4),CH(4,4),CHN(4,4),CHC(4,4),CHS(4)
      DIMENSION UPR(3),WPR(2),UEG(3),PUS(6),WUHF(2),PEPT(3),WEQ(3)
      DIMENSION DEL(4),CDEL(4)
      DIMENSION PRPUS(3)
      DATA WH / .233,.301,.198,.268 /
      DATA SHN / .03, .03, .045, .045 /
      DATA SHC / .3, .3, .35, .35 /
      DATA SHS / .2 /
      DATA (CH(1,I),I=1,4) / 1.0,1.0,1.2,.9 /
      DATA (CH(2,I),I=1,4) / 1.0,1.0,1.2,.9 /
      DATA (CH(3,I),I=1,4) / 1.1,1.1,1.32,.99 /
      DATA (CH(4,I),I=1,4) / 1.2,1.2,1.44,1.08 /
      DATA RCNORM,RSNORM / .2,.066 /
      DATA TEAMS,TRAINN,TRAINC,TRAINS / 25., .1E5, .3E5, .2E5 /
      DATA GUAC,EGC,EGS / 2.E4, 1.8E4, 1.2E4 /
      DATA CNO,CCO,CSO / .5E4, .5E4, .5E4 /
C
C                        TRANSMISSION COSTS PARAMETERS
      DATA UPR / 65., 30., 20. /
      DATA UEG / 30., 75., 30. /
      DATA WEQ / 8.E5, 5.E4, 4.E5 /
      DATA PUS / .5, .2, 1.0, 1.0, .2, .05 /
      DATA PRPUS / .5, 1.0, .05 /
      DATA WUHF / 1.E7, 5.E8 /
      DATA WPR / 6.E5, 8.E5 /
      DATA PDEP,PDPM,PDCPEP / .30, .15, .35 /
      DATA WMW / 5.E9 /
C
      DATA CGAP,CGFP,PFDRN / 25000., 20000., 100000. /
      DATA CHI,PWLD,ER / 16000., 400., 400. /
      EMGLTH = DELRC
C
C                        POLICY COSTS
C
      CGCON = CG61*(PFDRN + CGAP)*GCON
      CEMFDP = CGFP*EMFTOT
      CEMFDG = PWLD*ER*AMAX1(0.0,EMFTOT-GCON)
      CEMFD = CG61*(CEMFDP + CEMFDG)
      CGIMP = PWLD*ER*GIMTOT
      CPROG = CGCON + CEMFD
      CGSRU = AMAX1(0.0,CRUT*EMTRAN)
      CSTOR = AMAX1(0.0,CHI*EMSTOR)
      COSTGP = CPROG + CGSRU + CSTOR
C
C                        INFORMATION SYSTEM COSTS
C
C                        INITIALIZE PER UNIT COSTS
C
      DO 2 L=1,4
      CHS(L) = CH(L,4)*CG74
      DO 2 I=1,4
      CHN(L,I) = CH(L,I)*CG72
    2 CHC(L,I) = CH(L,I)*CG73
      SDRC1 = SDRC*RCNORM
      SDRS1 = SDRS*RSNORM
C
```

```
C                              COMPUTE DESIRED VARIANCES
C
      SDND2 = SDND*SDND + .1E-10
      SDRC2 = SDRC1*SDRC1 + .1E-10
      SDRS2 = SDRS1*SDRS1 + .1E-10
C                              INITIALIXE SUMS
C
      CSURN = 0.0
      CSURCU = 0.0
      CSURRU = 0.0
      SNUMNT = 0.0
      SNUMCT = 0.0
C                              INITIALIZE DELAY VALUES
      DEL(1) = CG71
      DEL(2) = CG75
      DEL(3) = CG76
      DEL(4) = CG77
C                              MAINTENANCE FACTORS
C
      PMNT = 1. + CG73
      PERT(1) = CG70 + PDEP
      PERT(2) = CG70 + PDCREP
      PERT(3) = CG70 + PDPM
C                              BEGIN COMPUTING MIN COST FOR GIVEN VARIANCE
      DO 5 I=1,4
      C1S = 0.0
      C2S = 0.0
      C3S = 0.0
      C4S = 0.0
      DO 6 L=1,4
      C1 = WH(L)*SHN(I)*SQRT(CHN(L,I))
      C2 = C1/CHN(L,I)
      C3 = WH(L)*SHC(I)*SQRT(CHC(L,I))
      C4 = C3/CHC(L,I)
      C1S = C1S + C1
      C2S = C2S + C2
      C3S = C3S + C3
      C4S = C4S + C4
    6 CONTINUE
C                              UNITS AND COSTS, BY CLASS, FOR SURVEILLANCE OF
C                                 NUTRITIONAL DEET AND FOOD CONSUMPTION
C
      SNUMN(I) = C1S*C2S/SDND2
      SNUMNT = SNUMNT + SNUMN(I)
      SNUMC(I) = C3S*C4S/SDRC2
      SNUMCT = SNUMCT + SNUMC(I)
      CSURN = CSURN + C1S*C1S
      IF(I.GT.3) GO TO 5
      CSURCU = CSURCU + C3S*C3S
    5 CONTINUE
      CSURN = CNO + CSURN/SDND2
      CSURCU = CCO + CSURCU/SDRC2
      CSURRU = C3S*C3S/SDRC2
C                              RURAL STORAGE SURVEILLANCE
C
      C5S = 0.0
      C6S = 0.0
      DO 7 L=1,4
      C5 = WH(L)*SHS*SQRT(CHS(L))
      C6 = C5/CHS(L)
      C5S = C5S + C5
      C6S = C6S + C6
    7 CONTINUE
      SNUMS = C5S*C6S/SDRS2
      CSURS = C5S*C5S/SDRS2
      CSURRU = CSURRU + CSO + CSURS
C                              FIXED SURVEILLANCE COSTS
C
      CFIXN = TEAMS*(TRAINN + QUAC*PMNT)
      CFIXCU = TEAMS*(TRAINC + EQC*PMNT)
      CFIXRU = TEAMS*(TRAINS + EQS*PMNT)
C                              TOTAL SURVEILANCE COSTS
C
      CYRSUR = CFIXN + CFIXCU + CFIXRU + EMGLTH*(CSURN/SAMPT +
     2         CSURCU/SMPRC + CSURRU/SMPRS)
C                              DELAY RELATED COST FUNCTONI
C                          POINTS ON CURVE
C
C
      CFIXTP = WM*PERT(3)*PUS(6) + UPR(3)*WPR(2)*PRPUS(3)
C
```

```
C                       ORIGINAL EQUIPMENT, PERSONNEL AND UHF
      CDEL(4) = UPR(1)*.PF(1)*PRPUS(1) + UEG(1)*.EG(1)*PERT(1)*PUS(1)
     2          + .UHF(1) * PERT(2)*PUS(2) + CFIXTR
C                       RADIOS FOR EACH TEAM, BASE, REGION
      CDEL(3) = CDEL(4) + UEG(2)*.EG(2)*PERT(1)*PUS(3)
C                       MINICOMPUTERS AND PERSONNEL FOR EACH BASE, REGIN
      CDEL(2) = CDEL(3) + UEG(3)*.EG(3)*PERT(1)*PUS(4) + UPR(2)*.PR(1)
     2                  *PRPUS(2)
C                       MODERNIZED UHF
      CDEL(1) = CDEL(2) + .UHF(2)*PERT(3)*PUS(2)
C
C                 INTERPOLATION
      J = 2
      IF(DELD.GT.DEL(1)) GO TO 12
      CDELD = CDEL(1) + (DEL(1) - DELD)*10.E10
      GO TO 20
   12 IF(DELD.GT.DEL(J)) GO TO 14
      CDELD = CDEL(J) + (CDEL(J-1) - CDEL(J)) * (DELD-DEL(J)) /
     2                    (DEL(J-1)-DEL(J))
      GO TO 20
   14 J = J + 1
      IF(J.LT.5) GO TO 12
      CDELD = CDEL(4)
   20 CONTINUE
      CDELD = EMGLTH*CDELD
C
C                       TOTAL INFORMATION SYSTEM COST
C
      COSTGX = CDELD + CYRSUR
C
C                       TOTAL COSTS
C
      COSTOT = COSTGP + COSTGX
      RETURN
      END
```

14:17:37 12/28/79   TB92117   1332 LINES PRINT.   19 PAGES PRINT.

BIBLIOGRAPHY

BIBLIOGRAPHY

(1) Abkin, Michael H., Policy Making for Economic Development: A System Simulation of the Agricultural Economy of Southern Nigeria. Unpublished PhD dissertation, Department of Electrical Engineering and Systems Science, Michigan State University, East Lansing, Michigan, 1972.

(2) "And now the horror of famine," Time, vol. 114, Ocotber 22, 1979.

(3) Anderson, M.A., "Use of height-arm circumference measurement for nutritional selectiviey in Sri Lanka school feeding," American Journal of Clinical Nutrition, vol. 28, July 1975.

(4) Arnold, R., "The QUAC stick: a field measure used by the Quaker Service Team in Nigeria," Journal of Tropical Pediatrics, vol. 15, December 1969.

(5) Benedict, Thomas R. and Bordner, George W., "Synthesis of an Optimal set of radar track-while-scan smoothing equations," IRE Transactions on Automatic Control, vol. AC-7, no. 4, July 1962.

(6) Berg, Alan, "Famine contained: notes and lessons from the Bihar experience," published in (7).

(7) Blix, Gunnar et al, Famine: A Symposium Dealing with Nutrition and Relief Operations in Times of Disaster. Uppsala, Sweden, The Swedish Nutrition Foundation, 1971.

(8) Box, M. J., "A new method of constrained optimization and a comparison with other methods," Computer Journal, vol. 8, 1965.

(9) Bradfield, R.B., "Early assessment of malnutrition," Nature, vol. 227, January 17, 1970.

(10) Burgess, H.H.L and Burgess, A., "A field worker's guide to a nutritional status survey," American Journal of Clinical Nutrition, vol. 28, November 1975.

(11) Cadzow, J.A., Discrete-Time Systems, An Introduction with Interdisciplinary Applications. Englewood Cliffs, New Jersey, Prentice-Hall, 1973.

(12) Census Organization, Projection and Estimate of Population of Bangladesh, Ministry of Home Affairs, Dacca, 1973.

(13) Cochrane, William G., Sampling Techniques (3rd Edition). New York, John Wiley & Sons, 1977.

(14) Committee Report, "Assessment of protein nutritional status," American Journal of Clinical Nutrition, vol. 23, June 1970.

(15) Davis, L. E., "Epidemiology of famine in the Nigerian crisis: rapid evaluation of malnutrition by height and arm circumference in large populations," American Journal of Clinical Nutrition, vol. 24, March 1971.

(16) Edwards, Ward, "How to use multiattribute utility measurement for social decision making," IEEE Transactions on Systems, Man and Cybernetics, vol. SMC-7, no. 5, May 1977.

(17) Field, John Osgood, "The soft underbelly of applied knowledge: conceptual and operational problems in nutrition planning," Food Policy, August 1977.

(18) Flores, M., "Dietary studies for assessment of nutritional status of populations in non-modernized societies," American Journal of Clinical Nutrition, vol. 11, November 1962.

(19) Gembicki, Floyd W. and Haimes, Yacov Y., "Approach to performance and sensitivity multiobjective optimization: the goal attainment method," IEEE Transactions on Automatic Control, December 1975.

(20) Greene, M. H., "Impact of the Sahelian Drought in Mauritania, West Africa," Lancet, June 1, 1974.

(21) Hoque, Anwaral, A System Simulation Approach to Policy Planning and Evaluation in the Context of Integrated Rural Development in Bangladesh. Unpublished PhD dissertation, Department of Agricultural Economics, Michigan State University, East Lansing, Michigan, 1977.

(22) Howard, R. A., "Information value theory," IEEE Transactions on Systems Science and Cybernetics, vol. SSC-2, no. 1, August 1966.

(23) Jelliffe, E. F. P. and Gurney, M., "Definition of the Problem," published in A. F. Roche and F. Falkner (eds.), Nutrition and Malnutrition, Identification and Measurement. New York, Plenum Press, 1973.

(24) Jelliffe, D. B. and Jelliffe, E. F. P., "The arm circumference as a public health index of protein-calorie malnutrition of early childhood," Journal of Tropical Pediatrics, vol, 15, December 1969.

(25) Joint FAO/UNICEF/WHO Expert Committee, Methodology of Nutritional Surveillance, WHO (United Nations) Technical Report Series 593, WHO, Geneva, 1976.

(26) Keyes, A., et al, The Biology of Human Starvation, vols, I and II. Minneapolis, The University of Minnesota Press, 1950.

(27) Kirk, Donald E., Optimal Control Theory, An Introduction. Englewood Cliffs, Prentice-Hall, 1970.

(28) Kleijnen, Jack P. C., "Design and analysis of simulations: practical statistical techniques," Simulation, March 1977.

(29) Kleijnen, Jack P. C., Statistical Techniques in Simulation, Parts I & II. New York, Marcel Dekker, Inc., 1974.

(30) Knapp, Allan G., "Computer simulation of seaport facilities," unpublished working paper, Department of Engineering Research, Michigan State University, East Lansing, 1977.

(31) Knapp, Allan G., "Information needed for famine relief," unpublished working paper, Department of Engineering Research, Michigan State University, East Lansing, 1978.

(32) Kolosa, K., private correspondence, December 1977.

(33) Kuester, James L. and Mize, Joe H., Optimization Techniques with FORTRAN. McGraw-Hill Book Company, New York, 1973.

(34) Lin, Jiguan G., "Multiple-objective problems: pareto-optimal solutions by method of proper equality constraints," IEEE Transactions on Automatic Control, October 1976.

(35) Llewellyn, R. W., FORDYN, An Industrial Dynamics Simulator. Raleigh, North Carolina State University, 1965.

(36) Lowenstein, M. S. and Phillips, J. F., "Evaluation of arm circumference measurement for determining nutritional status of children and its use in an acute epidemic of malnutrition: Owerri, Nigeria, following the Nigerian civil war," American Journal of Clinical Nutrition, vol. 26, February 1973.

(37) Manetsch, Thomas J., "On food shortage forecasting with emphasis on the South Asia case," unpublished paper, January 1977.

(38) Manetsch, Thomas J., "On the role of systems analysis in aiding countries facing acute food shortages," IEEE Transactions on Systems, Man, and Cybernetics, vol. SMC-7, no. 4, April 1977.

(39) Manetsch, Thomas J., private correspondence, September 1978.

(40) Manetsch, Thomas J. and Park, Gerald L., System Analysis and Simulation with Application to Economic and Social Systems, Parts I and II. East Lansing, Department of Electrical Engineering and Systems Science, Michigan State University, 1974.

(41) Manning, Diana H., Disaster Technology: An Annotated Bibliography. Oxford, Pergamon Press, 1976.

(42) Marr, J. W., "Individual dietary surveys: purposes and methods," published in G. H. Boure (ed.), World Review of Nutrition and Dietetics, vol. 13, New York, S. Karger-Basel, 1971.

(43) Martorell, R. et al, "Upper arm anthropometric indicators of nutritional status," American Journal of Clinical Nutrition, vol. 29, January 1976.

(44) Mass, N. J. and Senge, P. M., "Alternative tests for the selection of model variables," IEEE Transactions on Systems, Man, and Cybernetics, vol. SMC-8, no. 6, June 1978.

(45) Mayer, Jean, "Famine relief: what kind of organization and what type of trained personnel are needed in the field?," published in (7).

(46) Mayer, Jean, "Management of famine relief," Science, vol. 188, May 1975.

(47) Montgomery, Douglas C. and Bettencourt, Vernon M. Jr., "Multiple response surface methods in computer simulation," Simulation, October 1977.

(48) Myers, Raymond H., Response Surface Methodology. Allyn and Bacon, Inc., Boston, 1971.

(49) Nicol, B. M., "Causes of famine in the past and in the future," published in (7).

(50) Pakistan Ministry of Health, Nutrition Survey of East Pakistan, March 1962-January 1964, U. S. Department of Health, Education, and Welfare, Public Health Service, 1966.

(51) Payne, Harold J. et al, "An algorithm for bicriteria optimization based on the sensitivity function," IEEE Transactions on Automatic Control, October 1976.

(52) Raj, D., Sampling Theory. New York, McGraw-Hill, 1968.

(53) Report of the Indian Famine Commission, in D. G. Johnson, ed., Famine in India. New York, Arno Press, 1976.

(54) Samuelson, P. A., Foundations of Economic Analysis. New York, Atheneum, 1965.

(55) Saucedo, Roberto and Schiring, Earl E., Introduction to Continuous and Digital Control Systems. New York, MacMillan, 1968.

(56) Schweppe, Fred C., Uncertain Dynamic Systems. Englewood Cliffs, Prentice-Hall, 1973.

(57) Seth, K. L., Economic Prospects of Bangladesh. New Delhi, Trimurti Publications, 1972.

(58) Singh, K. Suresh, The Indian Famine 1967: A Study in Crisis and Change. New Delhi, People's Publishing House, 1975.

(59) Smith, Dennis E., "An empirical investigation of optimum-seeking in the computer simulation situation," Operations Research, vol. 21, 1973.

(60) Smith, Dennis E., Automated Response Surface Methodology in Digital Computer Simulation, vol. I. State College, Pa., Desmatics, Inc., 1975.

(61) Sokal, Robert R. and Rohlf, F. James, Biometry: The Principles and Practice of Statistics in Biological Research. San Francisco, W. H. Freeman and Company, 1969.

(62) Sommer, A. and Lowenstein, M. S., "Nutritional status and mortality: a prospective validation of the QUAC stick," American Journal of Clinical Nutrition, vol. 26, March 1975.

(63) White, Theodore H., In Search of History: A Personal Adventure. Harper & Row, New York, 1978.

(64) Wiehl, D. G. and Reed, R., "Development of new or improved dietary methods for epidemiological investigations," American Journal of Public Health, vol. 50, June 1960.

(65) Wilner, D. O. and Hendricks, C. D., The Design of a Low-Cost Two-Way Radio Communication Transceiver. Urbana, Charged Particle Research Laboratory, Department of Electrical Engineering, University of Illinois at Urbana-Champaign, 1974.

(66) Yarbrough, C. et al, "Anthropometry as an index of nutritional status," published in A. F. Roche and F. Falkner (eds.), Nutrition and Malnutrition, Identification and Measurement, New York, Plenum Press, 1973.

(67) Young, C. M and Trulson, M. F., "Methodology for dietary studies in epidemiological surveys. II - Strengths and weaknesses of existing methods," American Journal of Public Health, vol. 50, June 1960.

(68) Hafeez Zaidi, S. M., The Village Culture in Transition: A Study of East Pakistan Rural Society. Honolulu, East-West Center Press, University of Hawaii, 1970.

(69) Zerfas, A., "The insertion tape: a new circumference tape for use in nutritional assessment," American Journal of Clinical Nutrition, vol. 28, July 1975.