AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

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Batch 31

1. SUBJECT CLASSIFICATION

A. PRIMARY: Agriculture — AE10-0000-0000

B. SECONDARY: Agricultural economics

2. TITLE AND SUBTITLE

Some general principles of system modeling

3. AUTHOR(S)

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4. DOCUMENT DATE: 1975

5. NUMBER OF PAGES: 43p.

6. ARC NUMBER: ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

Mich. State

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

9. ABSTRACT

10. CONTROL NUMBER

PN-AAB-787

11. PRICE OF DOCUMENT

12. DESCRIPTORS

Models

13. PROJECT NUMBER

14. CONTRACT NUMBER

CSD-2975 Res.

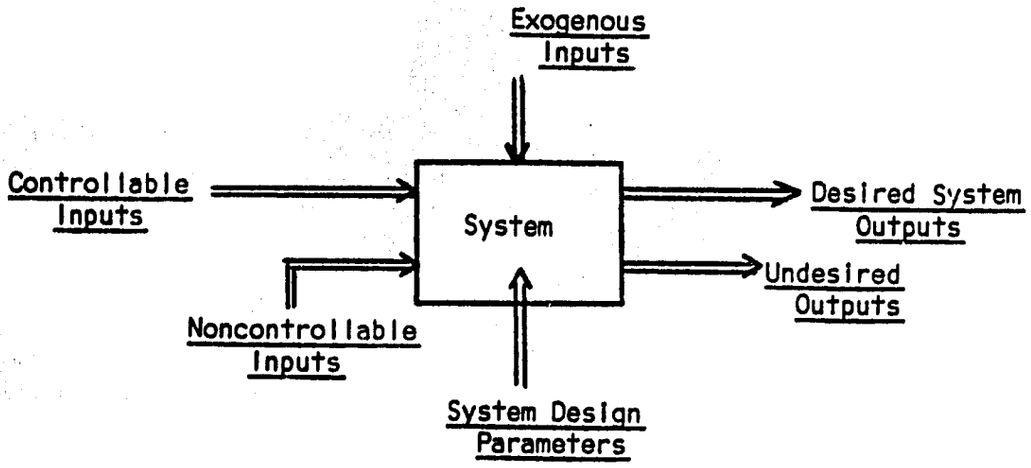
15. TYPE OF DOCUMENT

AID 590-1 (4-74)

CSD-2975 Rev.
PN-AAB-787
T. J. Manetsch
April 1975

Some General Principles of System Modeling

As discussed in Chapter II, the first step in system modeling is careful definition of the problem(s) the model is to address.[1/] This process identifies a number of variable sets that must be included in th model. These variable sets and their determination are discussed at length in Chapter II and are displayed here in Figure (1):



Variables Identified as Part of the Problem Definition Process

Figure (1)

[1/] This is part of the Feasibility Evaluation phase discussed in Chapter II.

In addition to defining these relevant variables to be included (insofar as feasible) in the system model, the problem definition phase produces at least a tentative definition of system boundaries. That is, it specifies what is to be treated as endogenous and what is to be treated as exogenous in the model and related analysis. This "system definition" is made in light of the perspective necessary to attain a useful solution to the problems being addressed. Whether or not this system definition leads to a feasible system model or not is a matter to be addressed when the model is formulated. Time and manpower constraints, gaps in available theory, etc. often restrict what can be included in system models. This interaction between the problem definition and the model building is one of many iterative loops in the problem solving process discussed in Chapter II.

Another useful function of the Feasibility Evaluation phase described in Chapter II is elimination of factors and approaches not feasible as means of attaining solutions to the real world problems which have been identified for solution. This aspect is important because it leads to simplifications in the system model.

Some Basic Questions to be Answered Before Beginning Detailed Model Development

Given that the Problem Definition and other phases of the Feasibility Evaluation process have been carefully carried out (not necessarily completed since this is an iterative procedure), a number of key questions must be answered before detailed model building can begin. These are discussed in what follows.

Time Frame. What model time frame is necessary to adequately study the relevant problems? Is a static model adequate? If not, what is the length of the time horizon that must be considered? At what time intervals

(simulated time) is information needed from the model? (Daily, monthly, yearly, etc.)

Level of Aggregation. What is the highest level of aggregation that will provide useable answers to the relevant problems? To dis-aggregate beyond what is needed is to increase model building and operating costs. Defining the level of aggregation required will usually shed light on the kind of model that is appropriate, e.g., discrete entity/event versus continuous flow models described by differential difference equations, etc.

Existing Models. What models or sub-models already exist that can be used in the given problem situation? Previous work, even if not useable directly, can often reduce model development time and cost substantially.

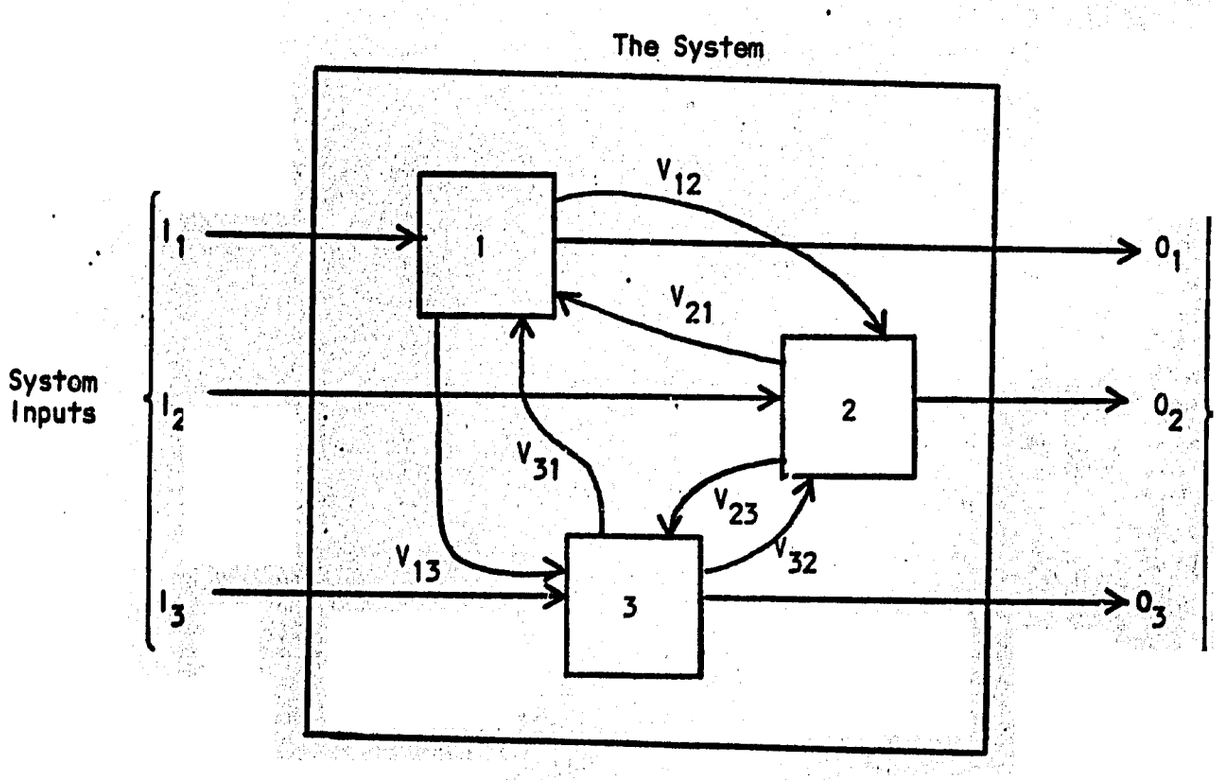
Model Decomposition. How should a large model be decomposed into sub-models? Decomposition is often necessary in order to expeditiously develop and de-bug a large model. Sub-models can be developed and tested independently before integration into the overall model. Experience has shown that this is much more efficient than attempting to develop a large model en toto. Further, if properly defined, sub-models can be delegated to different people (with different expertise) for development independently. This also can lead to efficiencies and quality in model development.

Model decomposition also can derive substantial benefits from the building block approach--well defined sub-models can be used in numerous different model applications. This area of model decomposition and the specification of "well defined" sub-models is a very important one. We will discuss this in more detail in the next section.

Some Principles of Model Decomposition

The Feasibility Evaluation provides the model builder with a detailed specification of the input and output variables of the overall model. The problem he faces at this point is the design of a model that will produce the specified outputs given the specified inputs. Decomposition identifies the relevant system sub-structures that interact to give the overall system its unique behavior. These sub-structures can often be modeled and tested independently as mentioned above.

This notion of system decomposition is illustrated in Figure (2):



System Decomposition

Figure (2)

The figure shows a system decomposed into three interacting sub-systems. Interaction takes place through the "interface" variables V_{ij}--the outputs of the ith sub-system that act as inputs to the jth sub-system. Figure (2) is equivalent to the following equations:

$$
1)\quad \begin{cases} O_1(t+DT) = f_1(x_1(t),\ I_1(t),\ V_{21}(t),\ V_{31}(t)) \\ O_2(t+DT) = f_2(x_2(t),\ I_2(t),\ V_{12}(t),\ V_{32}(t)) \\ O_3(t+DT) = f_3(x_3(t),\ I_3(t),\ V_{13}(t),\ V_{23}(t)) \end{cases}
$$

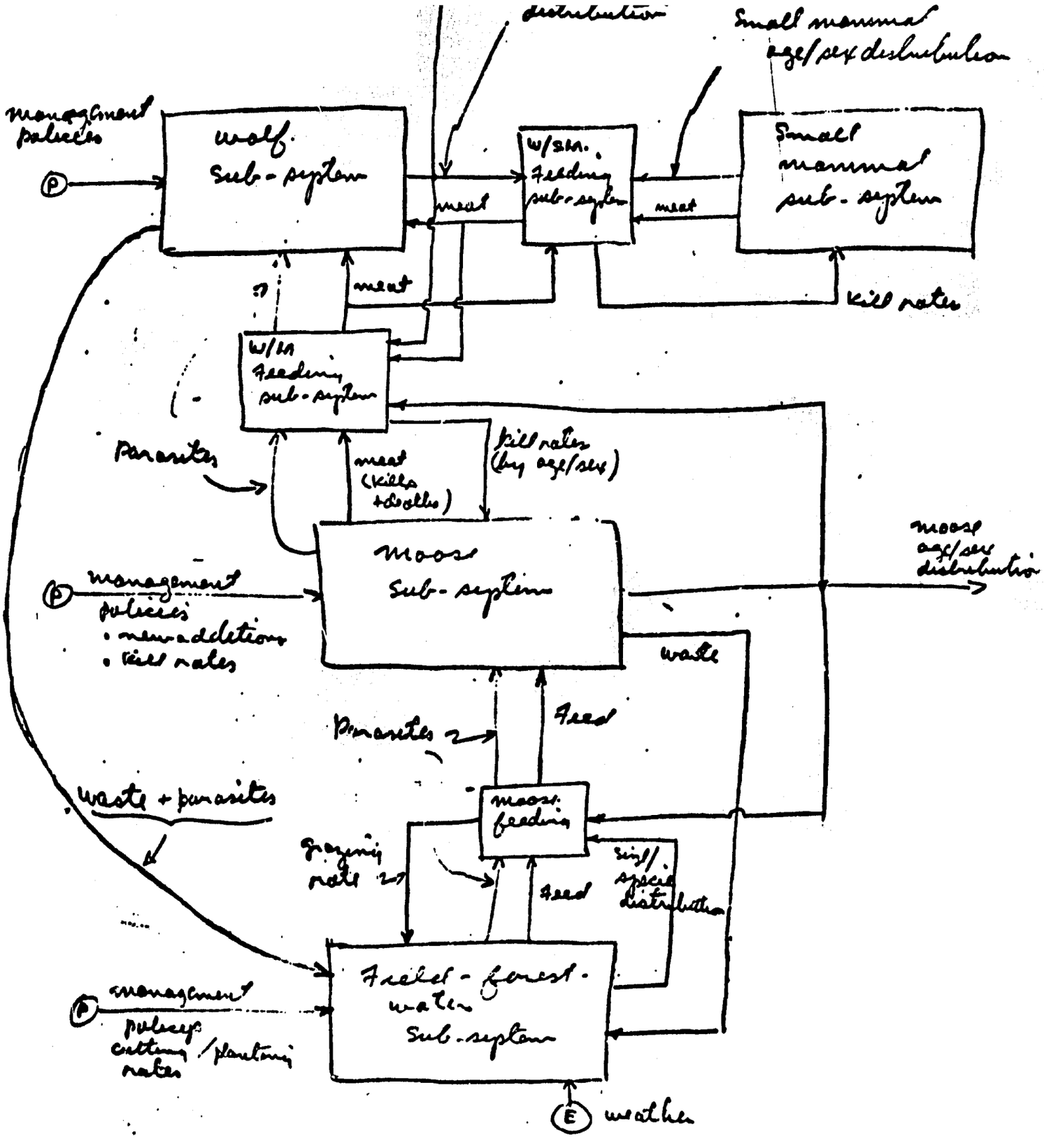
assuming a discrete time system or a discrete time approximation to a continuous-time system. (Continuous time state equations might be appropriate for (1) in some cases.)

In Equation (1) x_1, x_2 and x_3 are the vectors of state variables for sub-systems one, two and three. The functions f_1, f_2 and f_3 specify the equations which determine the structural interrelationships that determine outputs given inputs for each sub-system. The sub-system outputs which are inputs to other sub-systems are the following functions of sub-system inputs and state variables:

$$
2)\quad \begin{cases} V_{1J}(t+\Delta t) = f_{1J}(x_1(t),\ I_1(t),\ V_{21}(t),\ V_{31}(t)) \\ \qquad\qquad J = 2,3 \\ V_{2J}(t+\Delta t) = f_{2J}(x_2(t),\ I_2(t),\ V_{12}(t),\ V_{32}(t)) \\ \qquad\qquad J = 1,3 \\ V_{3J}(t+\Delta t) = f_{3J}(x_3(t),\ I_3(t),\ V_{13}(t),\ V_{23}(t)) \\ \qquad\qquad J = 1,2 \end{cases}
$$

System decomposition according to Figure (2) and Equations (1) and (2) has special and useful properties if the <u>structure</u> of each subsystem is independent of the structure of all other subsystems. (This means that f_1 is independent of f_2 and f_3, etc.). If we can define a system decomposition according to Figure (2) and Equations (1) and (2) that has

this independence property then it is possible to develop and test subsystem models independent of one another. These independently developed subsystem models can then be linked together through the interface variables to produce the overall model of the system. Subsystems or components of a system which are defined on the basis of the above conditions will be called "well-defined subsystems" or "well-defined components." An example of this kind of system decomposition taken from a natural system involving interacting flora and fauna in Isle Royale National Park is shown in Figure (3).



Slee moose/wolf/Flora System of Isle Royale
an Example of System Decomposition
Figure (3)

An Example of System Modelling

The purpose of this example is to give the reader further exposure to the modelling process in order to make it easier for him to learn to develop models himself. The subtitle of this discussion might well be "The Diary of a System Modeller" because to be useful our example must include the false starts, iterations and refinements that are a normal part of model development as a creative, learning process. We will begin with a primitive need for a model, work through (iteratively) a workable problem definition and eventually develop a system model, if it appears feasible to do so, which addresses the refined and expandedneeds that become apparent as we progress through the problem solving process.

First, a brief work about the choice of topic for this example. Three factors guided our choice. One consideration is its appropriateness as a problem amenable to modelling. A second is its relevance to a real world problem worthy of investigation. The third was sufficient familiarity with the subject matter of the problem to make study feasible.

Primitive Need Statement and Problem Definition

With food shortages on the horizon for many overpopulated countries due to shortages of basic foodstuffs and fertilizer on world markets and potential erratic production due to weather and climatic factors, there is a need to examine steps that governments can take to reduce the dimensions of potential crises for their people. In thinking further about this problem it is clear that in the event of a food crisis the range of actions by government and private decision makers is limited. Included in feasible courses of action might be:

Development of emergency food stockpiles by government during "fat" years.

Development of emergency food reserves by private individuals during "fat" years.

Government imports of food during a food emergency (a course of action that would probably be limited in scope by worldwide shortages)

Government confiscation of domestic food for redistribution during an emergency. This type of action can help soften the impact of the crisis upon people who are particularly vulnerable. (It's really not fair to include this aspect of the problem at this point. This policy action was thought of at a later point in the modelling process when a causal mop of system interrelationships was being thought through and developed.)

Quite clearly there is a relationship between food reserves available before a crisis and the human misery and starvation that result from acute food shortage. It is also clear that there are penalties associated with these food reserves--increased food prices and lowered standard of living during "fat" years and associated political repercussions, costs of holding and managing food reserves and other significant factors that may become apparent for inclusion in our thinking later. A system model might well be helpful in exploring some of these trade-offs.

In thinking about this problem over a period of several days some other aspects became clear. In developing countries with strong ties to the rural sector still in existence, (where food crises are most likely) we can infer some things about likely occurrences in the event of food crisis. It is clear that during times offood shortage, prices would soar and many middle to low income people with rural family ties would either back migrate to

rural areas where food supplies are more abundant or depend upon "CARE" packages from their rural relatives for survival. It is also clear that this increase in the number of people living directly off rural food sources will reduce the food supply available for shipment to urban markets. While the wealthy of the urban society will be able to purchase their food needs at inflated prices, this leaves lower income people without rural family ties in an extremely vulnerable position. It is this latter group that stand most in need of external assistance from government, etc.

With about this level of understanding of the problem work began on a somewhat more specialized but related problem. As part of a grain management system model for Korea, the author developed a model of urban food grain demand, storage, consumption, nutrition and the impact of malnutrition upon mortality rate. This work contributed to increased understanding of some of the details of the problem and serves to illustrate the point that the past experiences of the model builder provide him with raw material for developing new models. The contributions of this particular model building experience to our example will emerge as we get further into the modelling process.

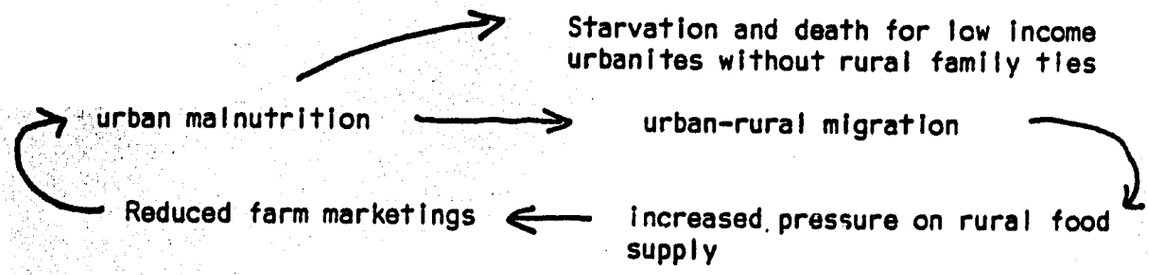
With this general understanding of the problem and the possible role a system model might play, a causal map of the major system interactions was developed to explore further the feasibility and usefulness of a system model for this problem.

A Causal Map for the System

One purpose for constructing a causal map of the system's major interactions was to consider further the feasibility and desirability of constructing a system model. At this point in the study the question of model feasibility was not answered and more exploration was necessary. Another benefit gained from developing the causal map (it turned out later) was increased

understanding of the problem and deeper insights into system behavior. The causal map of Figure (4) was developed in an hour or two interspersed with extended periods of mental rumination (rumination for illumination!).

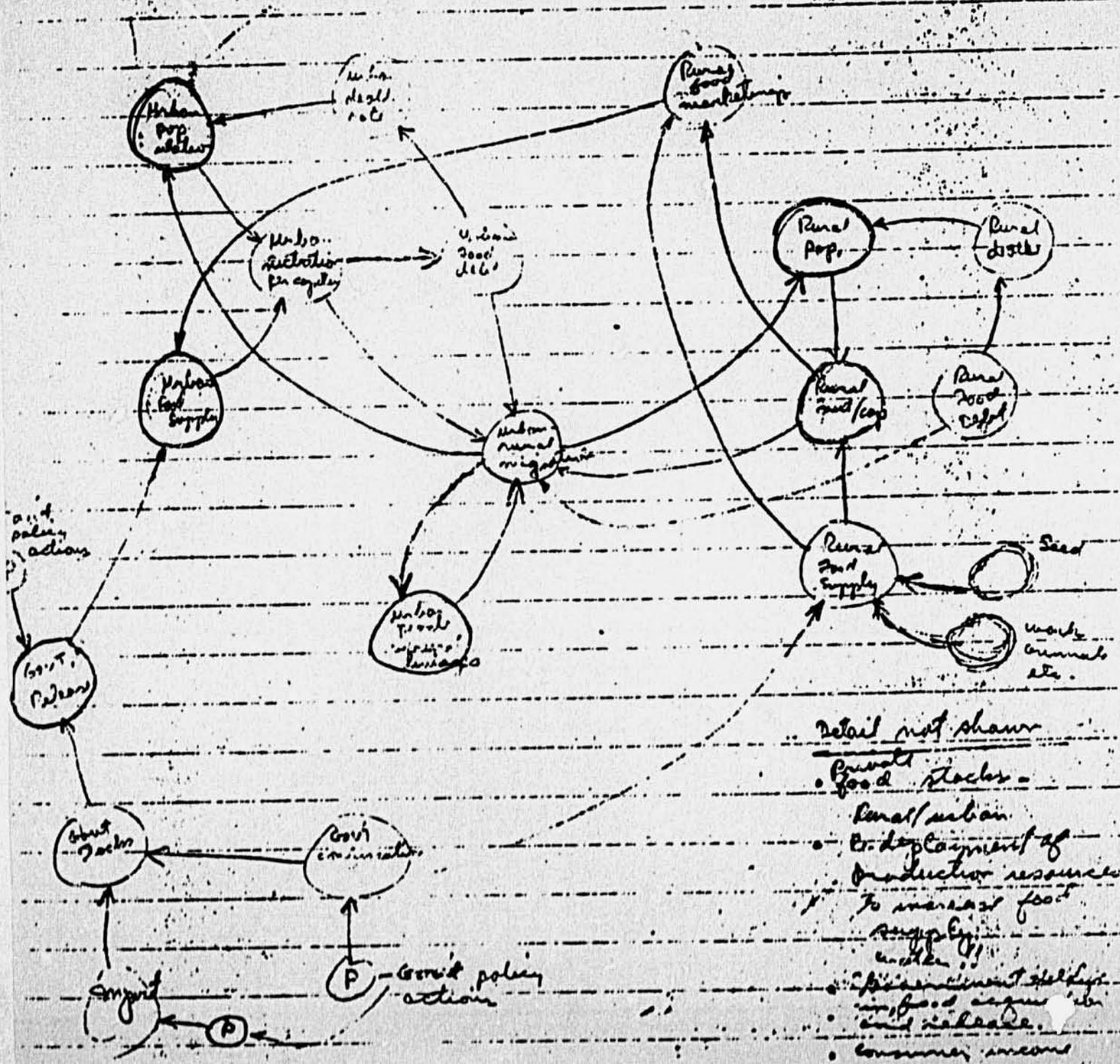
Central in this map of system interactions is urban-rural migration induced by deteriorating nutritional conditions in urban areas. There is, in fact, the possibility of an unstable feedback loop:



This series of interactions could lead to hoarding in rural areas, a drying up of farm food marketings, starvation and death for vulnerable urbanites and rampant disorder and food theft. Thinking along these lines led to the insight that government confiscations in rural areas, albeit a drastic measure, might be an important means of achieving a more equitable distribution of food and reducing the total impact of a food crisis. Further thinking about government food acquisition and distribution led to the insight that lags in information and action could be disastrous. With people shifting rapidly between urban and rural areas (and at times perhaps vice-versa in the net) it would be very easy to have food at the wrong places with respect to food needs. In developing this causal map it also became clear that there were other variables not included in Figure (4) which should enter or re-enter our thinking about this problem. These include:

- Private food stocks in rural and urban areas.
- Re-deployment of production resources to increase the food supply.

7/16/74 (10)



Detail not shown

- Private food stocks - Rural/urban
- Redeployment of production resources to increase food supply
- Government holdings in food acquisition and release.
- Consumer income classes.
- Food theft

A Preliminary causal map of interactions of the food supply - nutrition model

- Consumer income classes
- Food theft.
- Other sources of food, i.e. work animals, other animals, seed for planting, etc.
- Government delays in food acquisition and distribution.
- Effects of shortages of other nutritional elements besides calories, i.e. protein on human well-being and mortality.
- Geographic location of food stocks.
- Costs of "preventative medicine"--political disfavor, rising food prices, increased foreign exchange deficits and perhaps others.

(July 25, 1974, 12:00 noon)

(July 25, 1:30 p.m.) Where do we go from here? A couple of hours, some jogging and lunch have passed into history since writing the above on the causal map and related insights. At this point we could extol the benefits of exercise and relaxation for creative enterprises but let's just say that a couple of things have come into focus since last writing that will help in providing direction at this point. First, I'm quite confident at this point, from the foregoing that a system model for this problem is well worth developing further. I also have a new appreciation for the complexity of the problem and the model that will be required to cope with it adequately in particular countries. Clearly such a model is not feasible for our example here. I also am of the opinion from what we've learned so far in studying this problem and from past experience with models that we can get further useful insights by building a simplified macro model that emphasizes major interactions and omits selected detail. Furthermore, this kind of a model will provide us with the kind of vehicle we need to study and

illustrate the model building process. Therefore, the decision is made at this point to go ahead with a simplified system model that omits selected detail on the basis of judgement and the best information available. At this point we are also faced with the decision: how much outside expertise do we seek for this example model? While on the basis of my background I am familiar with many aspects of the problem--including food production, distribution, consumption and general demography, there are areas such as human nutrition in which my background is quite weak. For purposes of this example where and to what extent should I seek expert asistance? (July 25, 3:00 p.m.)

(September 3, 1974) Some vacation and participation in a lot of other matters have elapsed since writing the above. I will summarize briefly what has taken place on this project since July 25. Firstly, the decision was made to seek some expert help in the area of human nutrition/malnutrition before proceeding further with our model. I felt (again on the basis of past experience) that a few hours spent this way would pay significant dividends in terms of model quality and credibility. While my experience is far from an infallible guide, it led to some useful and inexpensive insights in this case.

A friend on campus who is an expert in physiology provided important observations and some basic journal articles dealing with effects of malnutrition on human beings. To summarize the key issues that affect our problem, it turns out that a model that deals with both calorie and protein difficiencies would be significantly better than one dealing only with calorie deficiencies. Research studies also indicate that calorie and protein deficiencies together are relatively good predictors of the adverse affects of malnutrition on human beings. It is therefore clear that any serious model for this

problem should include both calorie and protein deficiencies as dependent variables. Another significant point that emerged from this cursory study was that there are some serious non-fatal consequences of malnutrition in young children. Specifically, permanent damage to the central nervous system can result from severe but non-fatal malnutrition in young children. More than 90% of brain development takes place in the first four years of life and irreparable damage can be done by malnutrition during this critical period of growth. Clearly a model for this problem should seek to compute nutritional intakes for young children as endogenous variables.

Problem Definition Revisited

Modeling of these aspects (protein intakes and nutritional intakes of young children) requires a good bit of model detail but appears to be a feasible undertaking. Their inclusion here in an example model is not feasible however. We will focus our attention here on a three sector model including rural, urban, and government decision makers. The model will include only calories as the measure of nutrition and will not disaggregate populations by age and sex. Given these simplifications (which can be removed given time and resources) we will develop a model that includes as many of the factors and interactions discussed above as possible (see Figure (4) and related discussion).

These three sectors have been defined as above because this appears to be a "well defined" set on the basis of the earlier discussion (pp. 5&6) we might find that an additional sector or two will be required as the model develops but will start with these.

A General System Block Diagram

Figure (5) represents tha first iteration of a general system block diagram. The purposes of this diagram are:

- to explicitly define model components in terms of their input and output variables.
- to explicitly define the interactions among model components in terms of specific variables.
- to explicitly define the model exogenous variables and their point(s) of impact upon the system.
- to explicitly define policy variables (controllable inputs) and their point(s) of impact upon the system.
- to explicitly define the performance variables to be used by decision makers to evaluate system performance.

Note that this diagram is really a more detailed version of the "system identification" diagram discussed in Chapter II.

(November 12, 1974) Back to this after devoting attention to many other activities. (You can tell that this project is at the bottom of the priority list much of the time.) After re-reading the above relating to this food supply example it became clear that the block diagram of Figure (5) should include variables which provide measures of malnutrition by <u>income classes</u> particularly in urban areas. It is also clear that we should dis-aggregate the urban population according to whether or not people have rural ties that will provide them food in event of emergency. Changes were made in Figure (5) to include these factors (November 14, 1974). Another point that is becoming clear is that our model will require one or more new components. One, a "market" component, to provide food linkages among sectors and to generate market price of food and perhaps another to provide

migration linkages between the rural and urban sectors.

With the broad outlines of our model as depicted in Figure (5) let us begin detailed development of the model components which at this point include:

- The rural sector model
- The urban sector model
- The government sector model
- A market model
- Perhaps a component for interfacing migration flows

We will attempt to include the factors determined to be relevant to our problem in the above discussion (omitting population disaggregation by age groups and consideration of protein intakes to simplify somewhat). We recognize that our understanding of the problem is likely to improve and that we may make further modifications in our problem definition or in Figure (5).

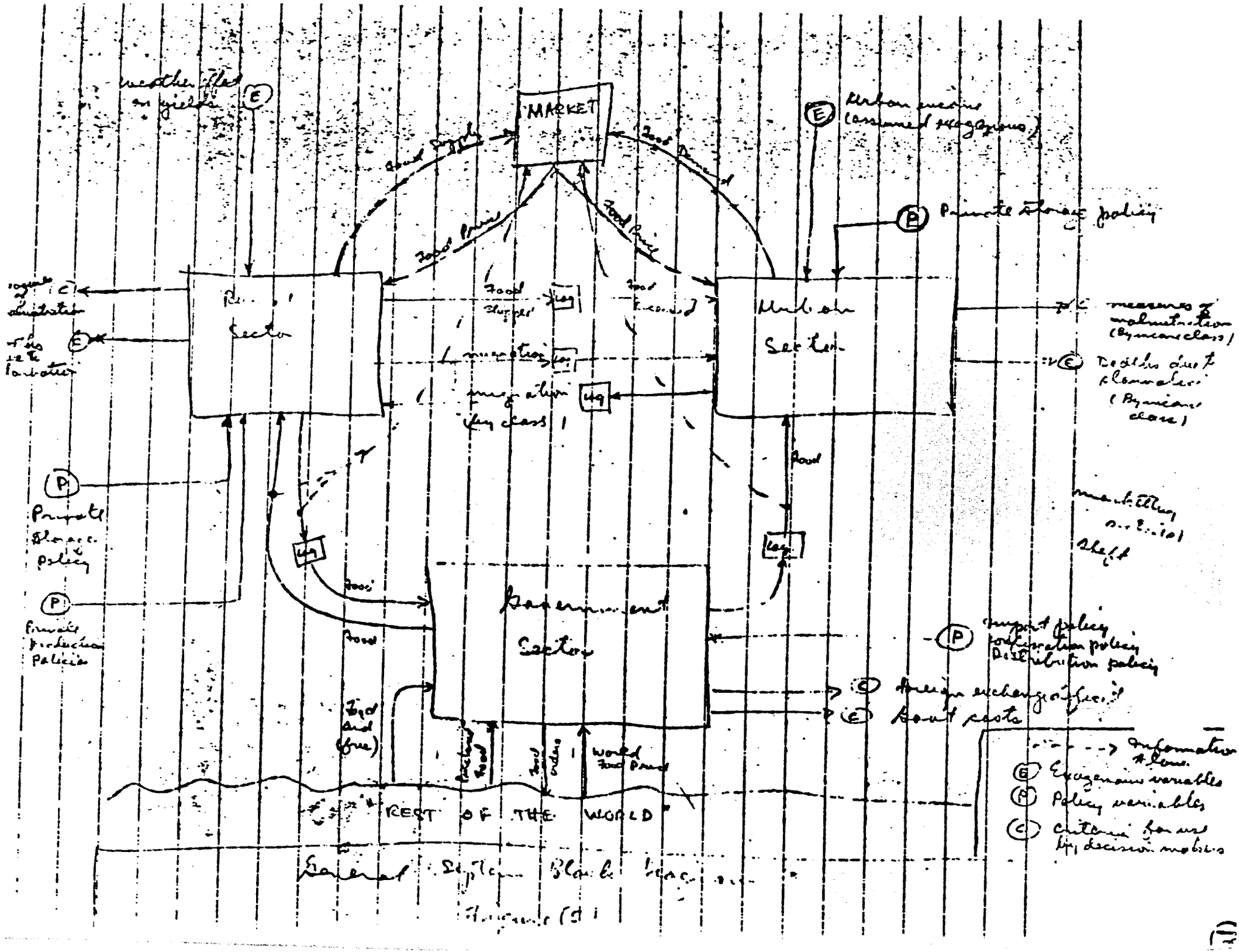
Detailed Model Development--A Beginning

Let us begin detailed model development with the urban sector (because most of the vulnerable people in the event of food shortage probably reside in urban areas, i.e. the primary needs we're dealing with are in this sector). Our objective will be to develop a model that will

i) take as inputs overtime the variables indicated in Figure (5).

ii) produce the urban sector output variables over time (including decision criteria) indicated in Figure (5).

A good place to begin is with the parts of the model that are best understood. This certainly includes population dynamics. We have essentially four urban populations with which to deal:


MARKET
Food Supply
Food Demand
Food Price
Food Price
Urban income (assumed exogenous)
Private storage policy
Rural Sector
Urban Sector
Food Supplied
Food Received
migration
migration (by class)
Food
Food
Food
Food
Government Sector
Private Storage policy
Private Production Policies
Food Aid (free)
Food orders
World Food Price
"REST OF THE WORLD"
measures of malnutrition (Bynicane class)
Deaths due to Bynicane (Bynicane class)
Import policy
Confiscation policy
Distribution policy
Foreign exchange deficit
Govt costs
Information flow
Exogenous variables
Policy variables
Criteria for use by decision makers

1) Lower income with no strong rural family ties.

2) Lower income <u>with</u> strong rural family ties.

3) Upper income with no strong rural family ties.

4) Upper income with strong rural family ties.

The equations which describe the population dynamics at this level of aggregation are straight-forward. In terms of first order difference equations, they are:

1) $PU_i(t+DT) = PU_i(t) + DT*(BR_i(t) + MIGIN_i(t) - DR_i(t) - MIGOUT_i(t))$

where:

PU_i = Urban population in i^{th} category ($i = 1, \ldots, 4$)

BR = Birth rate--persons/yr.

DR = Death rate--persons/yr.

MIGIN = In-migration (persons/yr.)

MIGOUT = Out-migration (persons/yr.)

The birth rates are functions of population sizes and per capita nutritional levels and can be approximated as:

2) $BR_i(t) = MIN[MAX[(B_{1i}(1 + B_{2i}* \left(\frac{PCONSU_i - RNUTP_i}{RNUTP_i}\right))), 0.], B_{1i}]PU_i(t)$ [1/]

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where:

B_{1i} = the normal birth rate for the ith population at normal levels of nutrition--proportion/yr.

$RNUTP_i$ = normal nutritional requirement for urban people in the ith category--MT (grain equivalent)/person-yr.

$PCONSU_i$ = actual nutritional intake of people in i^{th} urban population--MT (grain equivalent)/person-yr.

[1/] Ideally, BR should also be lagged to account for lags between nutritional levels and birth rates. While this is easy to do, we choose not to because this effect is of secondary importance and we choose to omit it for simplicity.

B_{2i} = % change in BR per % change in per capita nutrition

MIN, MAX = "minimum" and "maximum" functions, respectively

This birth rate function is shown in Figure (6) below:

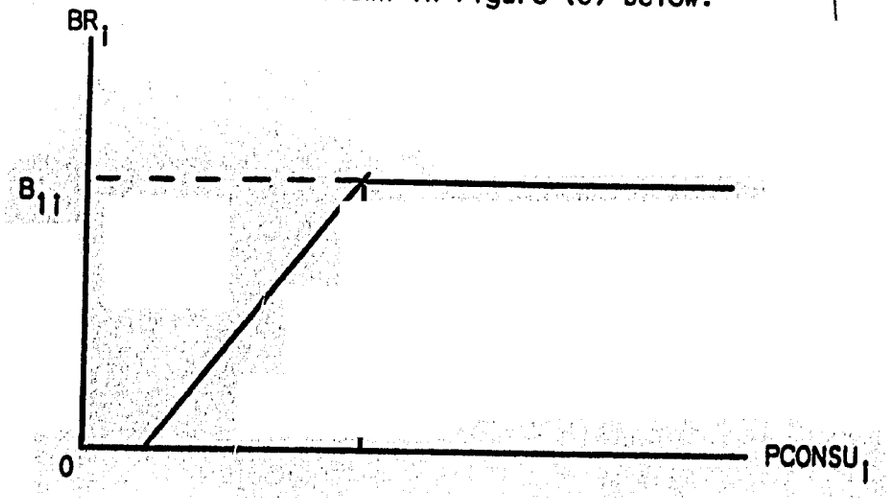


Figure (6)

The death rate, DR_i, is also a function of nutritional levels or, more precisely, the accumulated nutritional deficit per capita. It has been shown elsewhere[1/] that deaths due to malnutrition, DTHSM, can be computed as:

3) $DTHSM_i(t) = MAX[(PDTH(ANUTDP_i(t)) - PDTH(ANUTDP_i(t-DT)))\ PU_i(t),\ 0]$

where:

$DTHSM_i$ = deaths in population i in time interval (t-DT,t)

ANUTDP = average nutritional debt per person-MT grain/person

The variable PDTH(ANUTDP) is the cumulative probability of death at a given level of nutritional deficit, ANUTDP, and has the general shape shown on the next page in Figure (7).

[1/] Manetsch, T. J. "Consulting Report on Grain Management Model and Systems Science Training Based on a Field Trip to Seoul, Korea. 16-29 June 1974." Consulting Report. Seoul, Korea: Korean Agricultural Sector Simulation Project. June 1974.

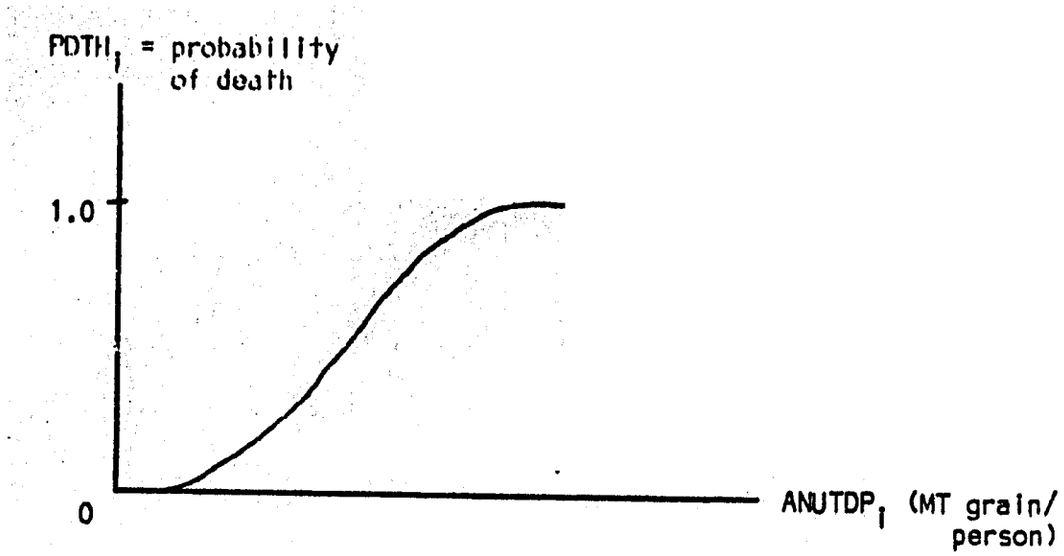


Figure (7)

Equation (3) is valid for modelling a <u>single</u> food crisis and the resulting impact upon deaths. It is not valid if, for example, the nutritiona debt (ANUTDP) decreases then increases again. More elaborate models are needed to handle these more general situations.

11/19/74 Given Equation (3) we can write an equation for the total death rate, DR_i, in Equation (1).

4) $DR_i(t) = DTHSM_i(t)/DT + DRO_i * PU_i(t)$

Here DRO_i is the normal proportion of deaths per year (in absence of malnutrition) and DT is the time increment used in the simulation mo

We also need to compute total deaths due to malnutrition:

5) $TDTHSM_i(t+DT) = TDTHSM_i(t) + DTHSM_i(t)$

We'll postpone development of equations for the in- and out-migration variables until more of the basic model structure is in place and turn our attention to modelling of nutritional intakes and nutritional debts.

Nutritional debts per-capita, $ANUTDP_i$, are computed by:

6) $ANUTDP_i(t+DT) = ANUTDP_i(t) + DT(RNUTP_i - PCONSU_i(t))$

where:

$RNUTP_i$ = nutritional requirement per capita in i^{th} population group--metric tons (grain equivalent) per person per year

$PCONSU_i$ = consumption per capita in i^{th} population group--metric tons (grain equivalent) per person per year

ANUTDP has units of MT per person.

Food can come to urban consumers by two means: purchases and emergency aid provided by government or private sources. Furthermore, consumers will in general have private food stocks upon which to draw at least for limited periods of time. We can write:

7) $PCONSU_i(t) = RNUTPN_i(t)*FU1$,

Where $RNUTPN_i$ is the normal (in absence of malnutrition) required food intake per person and FU1 is a function (≥ 0) depending upon the size of private food stocks. FU1 has the form shown below:

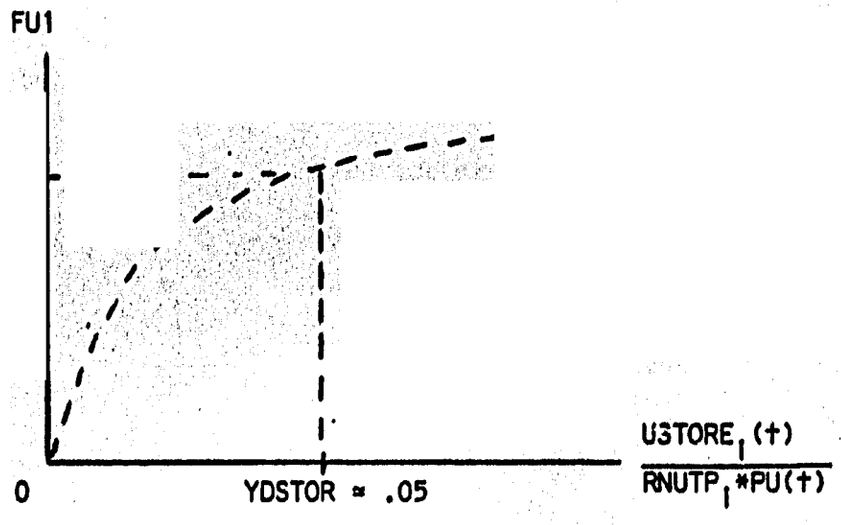


Figure (8)

12/5/74 The parameter YDSTOR is the normal desired storage level of urban people measured in years of consumption. (Usually this will be on the order of .05 indicating that families want to keep on hand something like a two week supply of food.) The variable $USTORE_i(t)/RNUTP_i*PU_i(t)$ has the units-years and represents the portion of year available food stocks will last at consumption equal to required levels. Figure (8) and Equation (7) say that when available food supplies drop below normal, levels consumers begin to cut their consumption.

Urban food storage, $USTORE_i$, is computed as:

8) $USTORE_i(t+DT) = USTORE_i(t) + DT*(UPUR_i(t) - CONSU_i(t) + EMFD_i(t))$

where:

$UPUR_i$ = urban purchases (MT/yr.)--from market model

$CONSU_i = PCONSU_i(t)*PU_i(t)$ = total consumption of ith urban population group--MT/yr

$EMFD_i$ = Emergency food from government or private sources (Determined in other components of the model.)

At this point, even this urban component model is beginning to get complex enough to warrant drawing a block diagram to aid in seeing interrelationships and to assist in further development of the component and linkages with other components. In Figure (9) we diagram the relationships developed thus far in solid lines.

12/6/74 After drawing the block diagram for Equations (1-8) we developed the rest of the structure of this model component. They appear in dashed lines in Figure (9). The primary objective here was the development of the necessary equations for computing $UDEM_i(t)$, the food demand of the ith urban population group. This variable enters the market component and affects the purchases ($UPUR_i$) the ith group makes in the market. The following equations compute urban demand as a function of appropriate

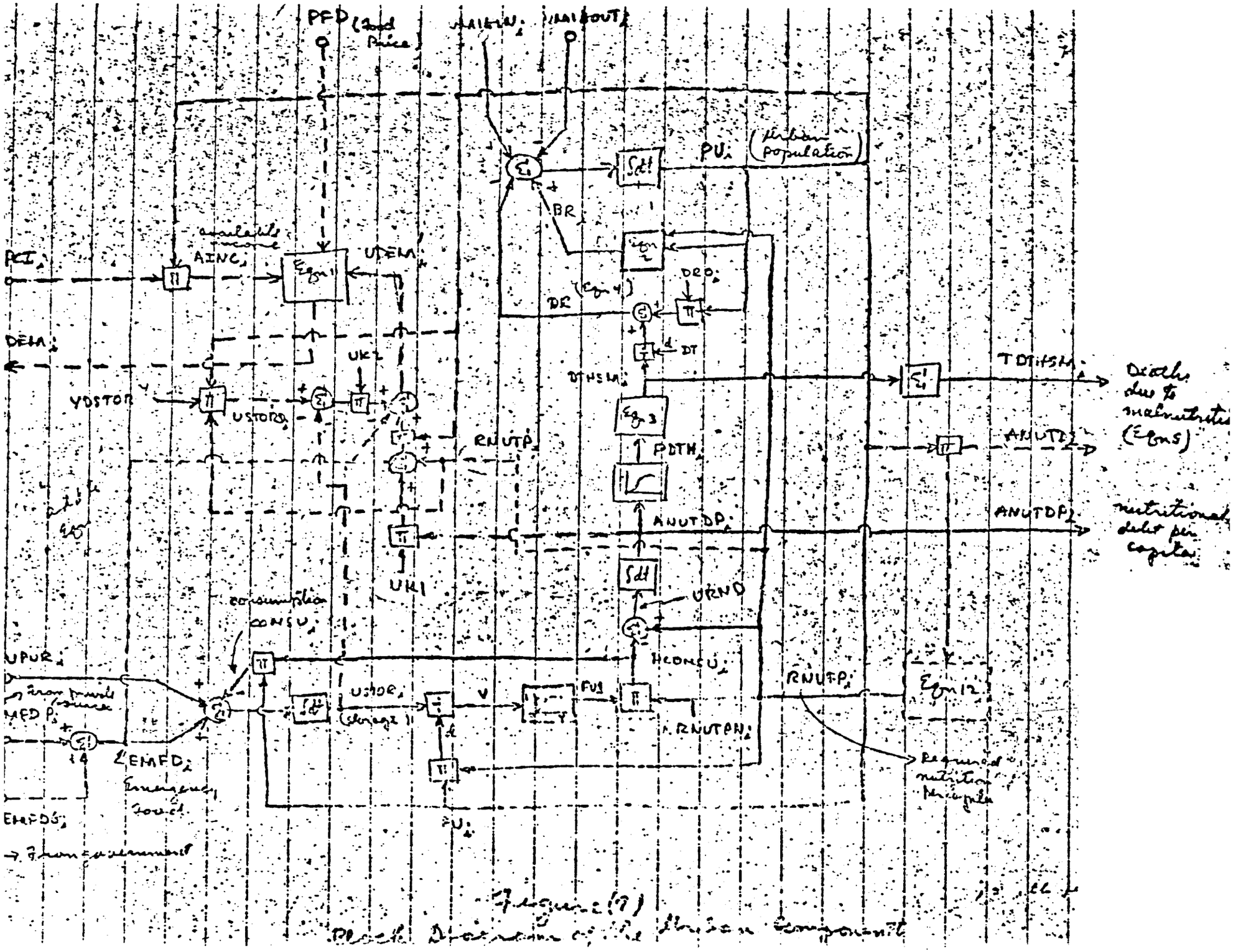


Figure (7)

Block Diagram of the Urban Component

variables (at this point it appears that income, food price, nutritional needs and storage deficits are "appropriate").

We begin by calculating urban demand in the absence of an income constraint, $UDEM_i'(t)$ (under extremely adverse conditions people may not be able to buy the food they need because of inflated prices).

9) $UDEM_i'(t) = (RNUTP_i + UK1*ANUTDP_i(t))PU_i(t) + UK2*(USTORD(t) - USTOR_i(t)) - EMFD_i(t)$

where:

$RNUTP_i$ = required nutrition--MT/person-yr.

$ANUTDP_i$ = nutritional debt--MT/person

UK1 = rate at which consumers wish to reduce nutritional debt--/yr.

PU_i = urban population--persons

$USTOR_i$ = urban storage--MT

$USTORD_i$ = desired urban storage--MT

$EMFD_i$ = emergency food received--MT/yr.

Desired urban storage is given by:

10) $USTORD_i(t) = YDSTOR*RNUTP_i*PU_i(t)$

where YDSTOR is the proportion of a year's consumption consumers wish to have on hand at any given time (≈ .05 years).

12/9/74 Given $UDEM_i'$ we now introduce the effect of available income upon food demand. At least initially a straight forward approach will be taken. Consider:

11) $UDEM_i(t) = UDEM_i'(t)$ if $UDEM_i'(t)*PFD(t) \leq UK3_i*AINC_i(t)$

$= UK3*AINC_i(t)/PFD$ if $UDEM_i'(t)*PFD(t) > UK3_i*AINC_i(t)$

where:

$UK3_i$ = the maximum proportion of available income that can be spent on food

$AINC_i$ = available income of ith class $/yr.

This says that a total food demand for the ith population group is inelastic until an income constraint is reached. Demand falls directly with the ratio $AINC_i/PFD$ as the income constraint is exceeded.

Another matter to be attended to before leaving the urban component is to make required nutrition per capita ($RNUTP_i$) dependent upon the nutritional debt. Importantly, nutritional requirements decrease as body weight decreases (due to a nutritional debt). This fact can have a substantial impact in making scarce food resources sustain an increased number of people. Up to a point, spreading food scarcity uniformly across a population can make the entire population more efficient in the use of nutritional intake and result in survival for the entire population (apart from normal attrition). An appropriate equation for modeling this effect is of the form:

12) $RNUTP_i(t) = MAX[(RNUTPN_i - UK4*ANUTDP_i(t)), UK5]$

where:

$RNUTPN_i$ = the normal nutritional requirement, MT/person-yr.[1/] (when the nutritional debt is zero)

UK4 = the change in nutritional requirement per unit of nutritional debt (MT/person-yr.)/(MT/person)

UK5 = minimum nutritional requirement MT/person-yr.

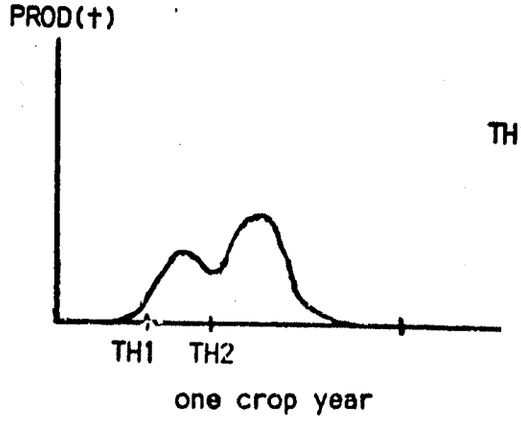
This will conclude our discussion of the urban component for the time being at least. We may find that we'll have to modify this part of the model later as things develop. We'll next consider the rural component because it will be easier to consider government and market components after the urban and rural components are structured.

[1/] MT = metric ton grain equivalent (lest thee forget)

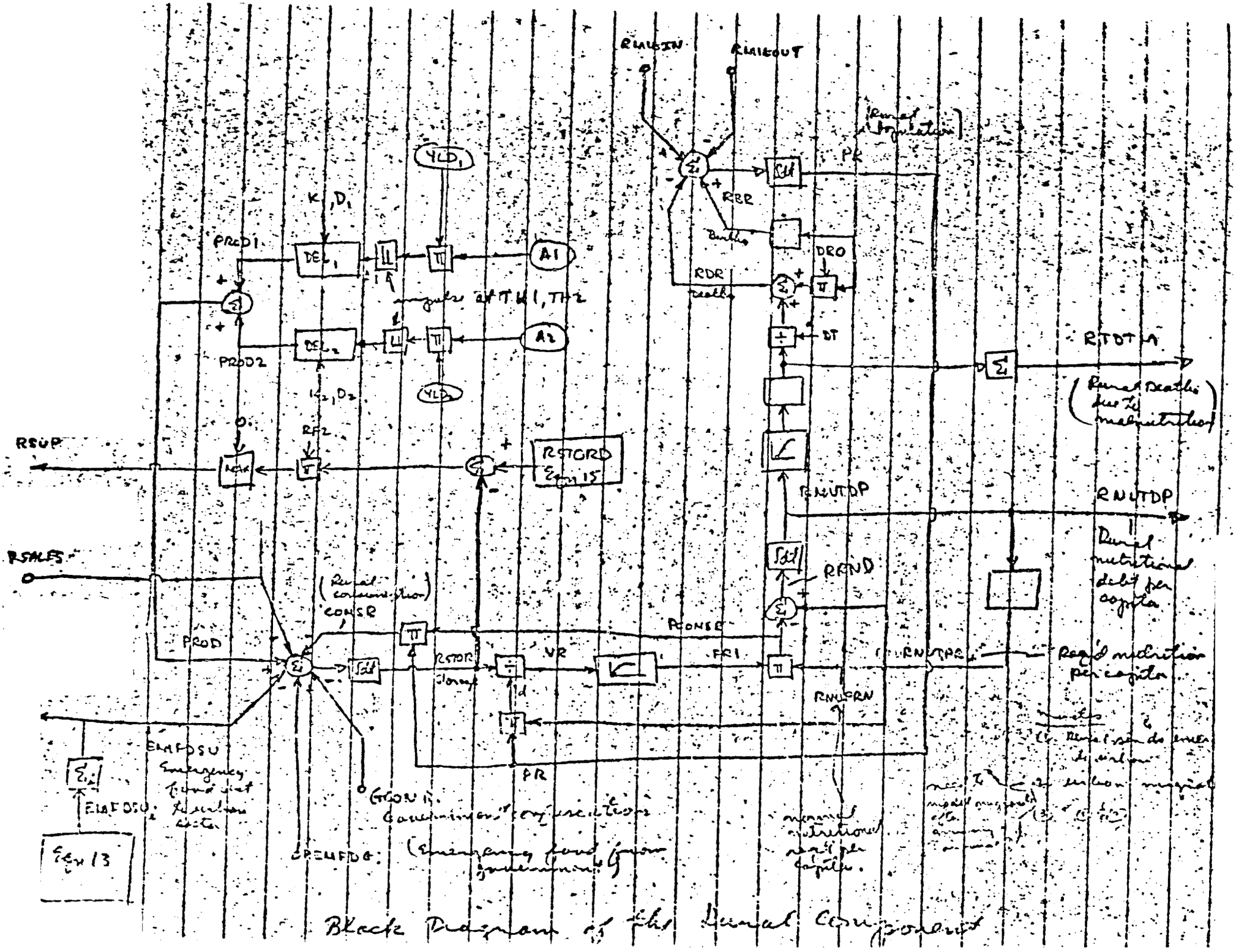
The Rural Component

12/10/74 The rural component includes production and sales as well as consumption and storage functions. We'll begin by developing some of the structural relationships in a block diagram that can be readily translated into model equations. The question arises at this point: How should the rural sector be disaggregated (if at all)? The need to disaggregate by income classes is not as pressing as in the urban sector since rural people are not as vulnerable to food shortages as are urban people. If there are a significant number of rural people who would be unable to feed themselves in the event of bad crops, then this type of disaggregation would be important in our particular problem. At this point we'll make the simplifying assumption that there is but one rural population.

The rural component block diagram is as shown in Figure (10). We began by drawing the structure that is identical to that of the urban component. That is the structure relating to food storage, consumption, nutritional debt, deaths due to malnutrition and population dynamics. Next we developed a simple mechanism for producing food (upper left portion of Figure (10).) This mechanism provides a seasonally fluctuating harvest (PROD) the magnitude of which is a function of area planted in two commodities (A1 and A2) and the yields of these commodities. Distributed delays DEL_1 and DEL_2 are used to produce harvests which occur at different times of the year (for example summer and fall). The variable PROD has the general shape over time appearing below:



TH1, TH2 = time of start of harvests one and two



Block Diagram of the Dual Component

in Korea the first peak would correspond to the barley harvest and the second to the rice harvest. In both crops we can introduce the impact of weather or other factors by writing appropriate equations for the yield variables.

1/6/75 Now comes the harder part. How do we develop equations that will simulate the behavior of rural people under conditions of food shortage? Specifically, we must develop model structure that will:

1) Describe how rural people react in meeting the food needs of their relatives living in urban areas

2) Related to 1), determine the quantity of food rural people are willing to sell on the market.

1/9/75 After giving some thought to 1) and 2) above, it seemed reasonable to assume that rural families would meet at least part of the food needs of their urban relatives before selling any surplus into the commercial market. We'll tentatively specify the following equations:

13) $EMFSU_i(t) = MAX[(FR1*(RK1*(PANUTD_i - RNUTDP) + RK2*PURND_i(t))PU_i(t)), 0.]$

where:

$EMFSU_i$ = emergency food sent by rural people to relatives in the ith urban population group--MT/yr. (i=2,4)

FR1 = a function similar to FU1 that reduces food shipments when rural stocks are low

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

$PANUTD_i$ = perceived nutritional debt of urban people in i^{th} population group (a lagged version of $ANUTDP_i$)--MT/person

$PURND_i$ = perceived rate of change of nutritional debt of urban people in i^{th} population group (MT/person-yr.)--this is an estimate of the difference between urban nutritional intake required and actual intake.

PU_i = number of people in the ith urban population group. (i=2,4

RK1 = a parameter ≥ 0 that determines the extent to which rural people seek to reduce the nutritional debt of their urban relatives

RK2 = a parameter that determines the extent to which rural people alleviate the perceived shortage in nutritional intake of their urban relatives ($0 \leq RK2 \leq 1$)

By adjusting the parameters in this equation we can introduce a wide range of assumptions regarding the degree to which rural people meet food needs of their urban relatives. The MAX function in this equation builds in the assumption that no private emergency food flows from urban areas to rural areas.

1/10/75 Now we consider modeling the behavior of rural people in supplying food to the commercial market. At the outset three factors appear to be of primary importance:

1) the amount of food available in rural storage to meet the consumption needs of rural people (and to some extent their urban relatives) until the next harvest period
2) the current market price of food, and
3) its rate of change.

We'll begin by considering the following equation for the most part taken from the Korean agricultural sector model.[1/]

1/13/75 At least tentatively we'll take rural food supply as:

14) RSUP(t) = MAX[RF2*(RSTOR(t) - RSTORD(t)), 0.]

where:

RSUP(t) = rural supply offered in commercial markets--MT/y

[1/] G. E. Rossmiller, et al., Korean Agricultural Sector Analysis and Recommended Development Strategies, 1971-1985, Michigan State University, 1972 (pp. 136).

RF2 = a function (possibly dependent upon price and its rate of change)

RSTOR(t) = rural food storage--MT

RSTORD(t) = rural food storage desired--MT (a function of consumption needs, time until next harvest period and market price--see Equation (15)).

This equation says that rural families will sell excess food (above what is needed to supply themselves and possibly their urban relatives until the next harvest period) if the price is right. The MAX function ensures that supply is non-negative.

A very important model equation is that which specifies the desired food storage of rural people, RSTORD. A tentative relationship is given as Equation (15):

15) RSTORD(t) = ((RNUTPR(t) + 1.*RNUTDP)*PR(t) + EMFDSU(t))*FR3*
TTSH(t)

where:

RSTORD = desired food storage of rural people--MT

RNUTPR = rural nutritional requirement (MT/person-yr.)

PR = rural population--persons

EMFDSU = emergency food sent to urban relatives--MT/yr. (see Equation (13))

FR3 = a function of food price that indicates the willingness of rural people to reduce food intake when prices are hig

TTSH = total time (in fractions of a year) remaining until the start of the next food harvest (when more food will become available).

1/15/75 In words, Equation (15) says that rural people desire in storage enough food to last themselves and their urban relatives (at a level of support specified by EMFDSU) until the start of the next harvest period.

This storage is also a (probably weak) function of market prices. The function FR3 has the general shape shown in Figure (11):

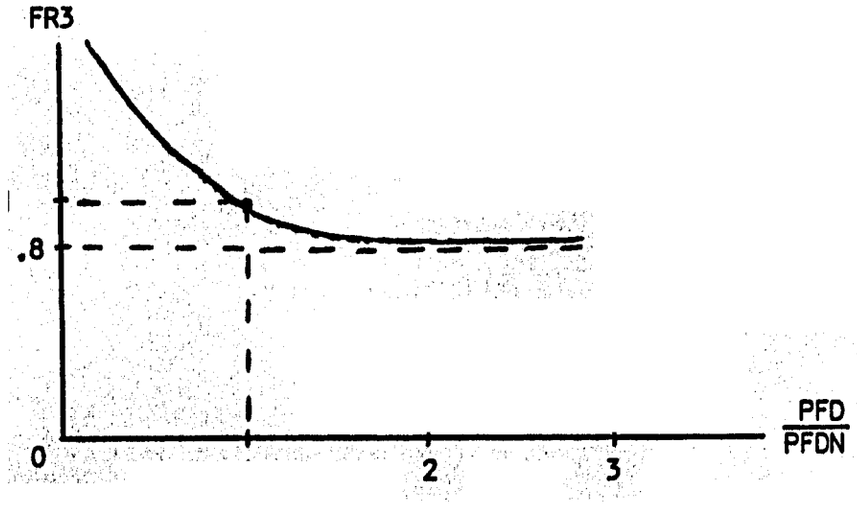


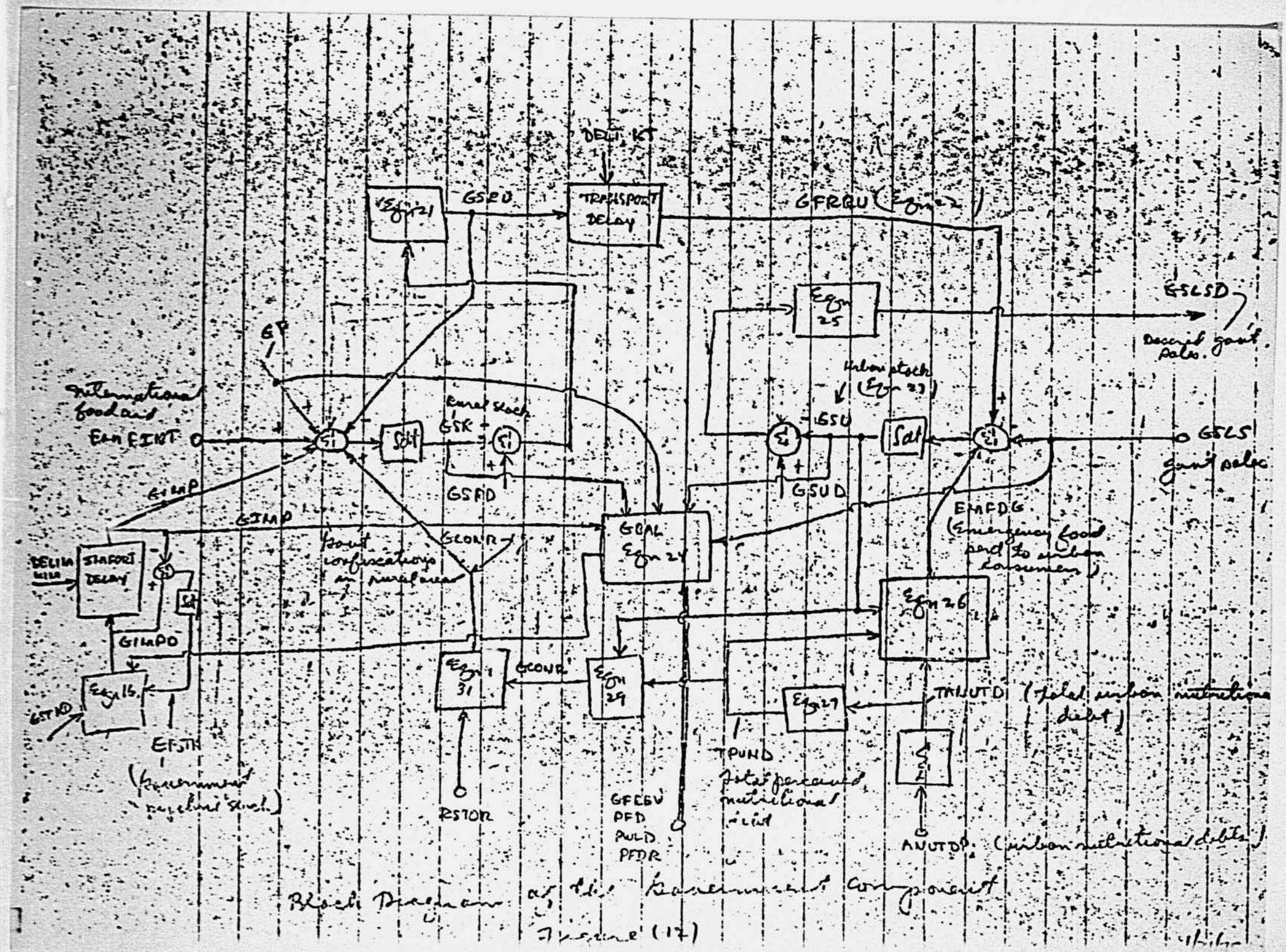
Figure (11)

The independent argument of this function is the ratio of current food prices to "normal" food prices.

The variable TTSH is simply the minimum of TTSH1 and TTSH2, the times to the start of harvests of food crops one and two.

The Government Component

We are now in a position to develop a tentative model for the government component. In accordance with our problem definition, this component must provide for food imports, sales of food into the domestic market, food storage in rural and urban areas, and food confiscation in extreme circumstances. The component must allow for delays in food transport and in information flows. It must also compute government financial variables important in determining its transactions in food or important



Block Diagram of the Government Component

Figure (17)

as criteria for decision makers to evaluate. A block diagram describing some of these interrelationships appears in Figure (12). (We choose to begin our modeling of this component by sketching in block diagram form a set of internal relationships that will interrelate the government sector inputs and outputs shown in Figure (5)).

1/24/75 There is a hierarchy of government decisions to be modeled specifically in the component. (The model should, however, permit the model user to explore a reasonable range of alternative decision rules). The hierarchy of decisions we must model consists of the following:

1) Determination of food import orders as national needs and resources dictate.
2) Decisions which ship food back and forth between rural and urban government stockpiles as urban and rural food needs dictate.
3) Determination of domestic government food purchases and sales.
4. Government confiscations of food in times of extreme emergency.

We must now develop explicit mathematical relationships to model these decisions.

Consider first the decision determining the rate of food import.

16) $GIMPO(t) = GIK(GSTKD(t) - GSTK(t) - GPSTK(t)) + GNSLS(t)$ if $GBAL > 0$

$= 0$ if $GBAL \leq 0$

where:

GIMPO = import orders (MT/yr.)

GSTK = government food stock (MT) on hand (sum of rural stock GSR plus urban stock GSU)

GSTKD = desired level of government food stock (MT)

GPSTK = government stock in import "pipeline"

G1 = a function with general shape shown in Figure (13)

GNSLS = normal domestic government sales and/or releases (MT/yr.)

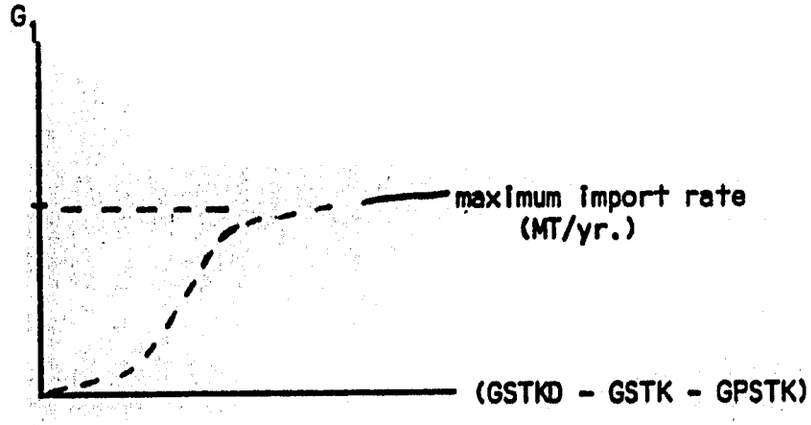


Figure (13)

This relationship orders imports whenever food stocks fall below desired levels. It also prevents importation when government resources (GBAL) do not permit. A question here is "how is desired stock level, GSTKD, determined"? The answer depends upon how the government values reserve stocks of food. Ideally substantial reserve stocks are desirable for future emergencies--but reserve stocks cost money to maintain and there may be short run food shortages (or high prices) that clamor for depletion of government stocks. We will tentatively assume that government desired stock levels are fixed at some point that reflects compromise between these conflicting factors. Therefore we take:

17) GSTKD(t) = constant at some value set by policy.

2/24/75 Given import orders as determined by Equation (16) we introduce the importation delay by means of a distributed lag. GIMP, government imports--MT/yr., is therefore computed from:

18) CALL DELAY(GIMPO, GIMP, RI, DELIM, DT, KIM)

DELIM represents the total delay between the sending of orders for imported food and the arrival of food in government warehouses in rural areas (presumably near ports).

Given GIMPO and GIMP as computed above we can compute the government "pipeline" stock (needed in Equation (16)) as:

19) GPSTK(t+DT) = GPSTK(t) + DT*(GIMPO(t) - GIMP(t))

GPSTK is the quantity of food ordered but still in the "pipeline," that is, in the process of being delivered to government warehouses.

Government stocks in rural areas are computed as:

20) GSR(t+DT) = GSR(t) + DT(GIMP(t) + GP(t) + EMFINT(t) + GCONR(t) - REMFDG(t) - GSRU(t))

where:

GSR = government food stocks in rural warehouses (MT)

GIMP = food imports arriving at government warehouses (MT/yr.)

GP = government food purchases (MT/yr.)

EMFINT = emergency food arriving from international sources (MT/yr.)

GCONR = government confiscation of food in rural areas (MT/yr.)

REMFDG = emergency food supplied in rural areas (MT/yr.)

GSRU = government food shipment from rural to urban warehouses (MT/yr.)

We must define explicitly (mathematically) each of the above (GP, EMFINT, ..., GSRU). Let us begin with GSRU. Normally food flows from rural to urban areas to meet the needs of urban consumers. Hence we expect that food not needed to maintain rural stock levels is rapidly trans-shipped to urban warehouses for release through (normally) private marketing channels. We will therefore take:

21) GSRU(t) = MAX[CG1*(GSR(t) - GSRD(t)), 0.]

GSRD is the desired government rural stock level and the parameter CG1 determines how rapidly the bureaucratic decision process responds in making stock adjustments. It can also account for lags in processing and handling. The MAX function prevents shipments from becoming negative (an impossible condition).

We use a distributed delay to model the transport delay in shipping food to urban warehouses so GFRRU (food received at urban warehouses) is calculated from:

22) CALL DELAY(GSRU, GFRRU, RTRU, DELT, DT, KT)

2/26/75 Before going further into government decision making determining food flows we will develop equations for government food stocks in urban areas and the level of government budget available for food transactions.

23) GSU(t+DT) = GSU(t) + DT*(GFRRU(t) - GSLS(t) - EMFDG(t))

where:

GSU = government food stocks in urban areas (MT)

GFRRU = government food shipments received from rural warehouses (MT/yr.)

GSLS = government sales into urban markets (MT/yr.)

EMFDG = government emergency food released to urban area

2/28/ 24) GBAL(t+DT) = GBAL(t) + DT*(GSLS(t)*PFD(t) + GFREV(t) - GIMP(t)*PWLD(t)*ER - CHI*(GSR(t) + GSU(t)) - GP(t)*PFDR(t))

where:

GBAL = government balance in food account--Won

GSLS = government sales in rural areas--MT/yr.

PFD = food price in urban areas--W/MT

GFREV = government revenue into food account--W/yr.

GIMP = government imports--MT/yr.

PWLD = world food price--$/MT

ER = exchange rate--W/$

CHI = cost of holding inventory--W/MT-y

GP = government purchases--MT/yr.

PFDR = rural food price--W/MT.

Before going further we must establish a reasonable and consistent strategy for government to follow in determining:

1. Food imports (GIMP)
2. Sales into urban markets (GSLS)
3. Emergency food distributed into urban areas (EMFDG)
4. Emergency food distributed into rural areas (REMFDG)
5. Food confiscations in rural areas (GCONR)
6. Government food purchases (if any) in rural areas (GP)

A "reasonable" approach would be one adapted to the seriousness of the domestic food situation--relatively normal market operations when the domestic situation is near normal going to mere drastic action only when serious food shortage dictates.

3/3/75 We have already tentatively specified a relationship for government imports (Equation (16)) consider now government sales GSLS. Normally the objective of the government will be to move food into urban areas where it is needed (apart from short run strategies to reduce seasonal price fluctuations). We will therefore take government <u>desired</u> sales, GSLSD, as some proportion of the urban stock level in excess of a desired value. (Desired sales are in general different from actual sales because of the fact that the government may not be able to sell all it wishes at prevailing prices).

25) GSLSD(t) = MAX[CG2*(GSU(t) - GSUD), 0.]

where:

GSLSD = desired government sales (in urban areas)--MT/yr.

GSU = urban food stock--MT

GSUD = desired government urban stock level--MT

The MAX function eliminates the possibility of negative sales.

3/5/75 In the event of a food crisis urban prices soar and the government may not be able to sell the amount GSLSD (and perhaps only a small fraction of this amount). In that case they may resort to emergency food distributions if food stocks are available and if the severity of the situation warrants. We will tentatively postulate the following relationship for emergency food releases into urban areas:

26) EMFDG(t) = MAX[(CG3*GSU(t)*(TPUND(t) - TPUND0)), 0.]

where:

TPUND0 = a threshold level of nutritional debt

TPUND = the total perceived urban nutritional debt given by:

3/7/75 27) TPUND(t+DT) = TPUND(t) + (DT/CG4)*(TANUTD(t)*GDE - TPUND(t))

where:

TANUTD(t) = the total urban nutritional debt computed as:

28) $TANUTD(t) = \sum_i ANUTDP_i(t)$

the sum of nutritional debts for the several different urban populations. The parameter GDE accounts for government errors in estimating nutritional debt, i.e., GDE > 1 results in overestimation, etc. Equation (27) also introduces an exponential lag into the estimation of nutritional debt and CG4 is the parameter that determines the length of this lag.

We turn now to simulation of government food confiscations in rural areas GCONR. Consider:

29) GCONR'(t) = MIN[MAX[CG5*(TPUND(t) - TPUND1)(GSU1 - GSU), 0.], GCONMX]

3/12/75 This equation says that government will seek to confiscate food in rural areas at the rate CGONR' when:

a) the perceived urban nutritional debt is in excess of threshold TPUND1 and

b) government urban stocks are below desired value GSU1.

The MIN and MAX functions in Equation (29) insure that GCONR' is greater than zero but less than an upper limit, GCONMX (MT/yr.).

Actual confiscations result from introducing a lag and a constraint based on the availability of food in rural areas (to confiscate).

30) GCONR'(t) = 0 if RSTOR < RSTORM

where:

RSTOR = rural food storage (MT)

RSTORM = a minimum level of rural food storage

31) GCONR(t+DT) = GCONR(t) + (DT/CG6)*(GCONR'(t) - GCONR(t))

The parameter CG6 determines the length of time that elapses between a government decision to confiscate food and the arrival of confiscated food at a rural government warehouse. This food must then be transshipped to an urban warehouse through the mechanism described in Equation (21).

Programming What We Have So Far

3/13/75 At this point I'll begin programming the model (even though the structure of the relatively simple market component has not been specified). A good way to review and perhaps refine the structure that has been specified is to begin programming it. I need this review now as it difficult to keep enough of the model in my head to make further development

possible. I'll begin programming the government component because it's freshest in my mind. I'll use SIMEXI as a founcation for a FORTRAN-FORDYN model. The government component will be programmed as a subroutine of the SIMEXI executive.

4/16/75 Since writing last, much of the model has been programmed in FORTRAN. We now need equations for a market component so the programming can be completed.

Market Component

A market component is needed to compute actual food transactions among buyers and sellers and to compute market price over time. Specifically, this component must interrelate the input and output variables shown in Figure (14):

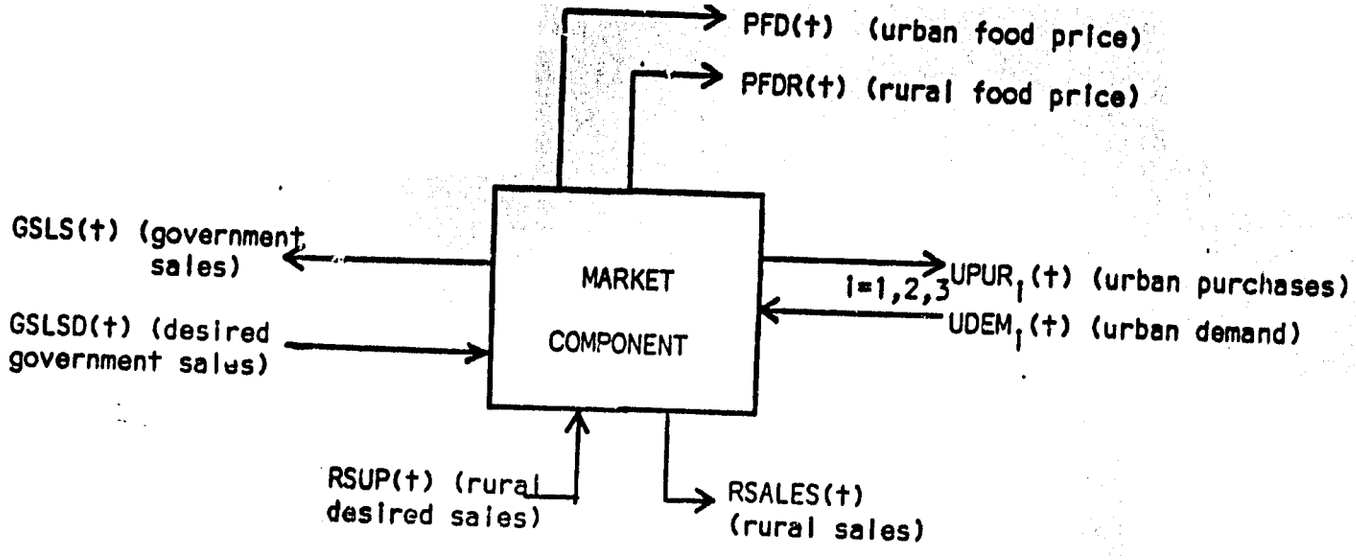


Figure (14)

4/22/75 The food market price mechanism (a competitive one) is modeled by a Walrasian equation wherein:

32) $\frac{dPFD(t)}{dt} = CM1*(\frac{DEM(t) - SUP(t)}{DEM(0)})*PFD(t)$ (PFD = urban food price $

DEM here is aggregate demand given by:

33) $DEM(t) = \sum_{i=1}^{3} UDEM_i(t)$

the sum of the demands from the several income classes. SUP(t) is aggregate supply given by:

34) $SUP(t) = GSLSD(t) + RSUP(t)$

the sum of government and rural desired sales. Equation (32) says that urban food prices, PFD, move in response to excess demand. The multiplicative term PFD on the right of (32) makes price increases for a given % excess demand proportional to current price levels (as market behavior indicates should be the case). CM1 is a constant model parameter.

In determining the transactions that clear the market several cases arise:

a) $DEM(t) \geq SUP(t)$ (The normal case during a food shortage)

In this case sellers can sell at their desired rates and

35) $GSLS(t) = GSLSD(t)$ (MT/yr.)

$RSUP(t) = RSALES(t)$ (MT/yr.)

On the demand side, however, buyers are not able to acquire food at desired rates. We will assume here that high income people (by being able to outbid other consumers) have top priority in satisfying their demand. Hence:

36) $UPUR_3(t) = MIN(SUP(t), UDEM_3(t))$

We further assume that any remaining supplies $(SUP(t) - UPUR_3(t))$ are divided between consumers in groups 1 and 2 in proportion to their demands $(UDEM_1(t)$ and $UDEM_2(t))$:

$$37)\quad UPUR_i(t) = \frac{UDEM_i(t)(SUP(t) - UPUR_3(t))}{\sum_{i=1}^{2} UDEM_i(t)} \qquad i=1,2$$

The second major case arises when:

b) $DEM(t) < SUP(t)$

In this case consumers are able to realize their consumption plans and

$$38)\quad UPUR_i(t) = UDEM_i(t) \qquad i=1,2,3$$

We will assume that actual sales in the market split between farmers and government on the basis of desired sales:

$$39)\quad RSALES(t) = \frac{DEM(t)*RSUP(t)}{RSUP(t) + GSLSD(t)} \qquad \text{(rural sales MT/yr}$$

$$40)\quad GSLS(t) = DEM(t) - RSALES(t) \qquad \text{(government sales MT/yr.)}$$

Finally, we compute rural prices as a simple proportion of urban prices thus assuming a constant proportion markup:

$$41)\quad PFOR(t) = CM2*PFD(t) \qquad C1 < CM2 < 1$$

These equations are readily programmed as a FORTRAN subroutine. In this form they constitute a model component that interacts through time with the other components discussed.

This completes our first iteration description of the structure of the model. We will now complete programming, assign tentative values to model parameters and initial conditions and move toward tests of this tentative structure. Model tests will undoubtedly lead to detection of conceptual errors and to improvements which can improve model realism and usefulness.