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Optimal Farm-to-Market Transportation and Storage of Certain Agriculture Commodities: Bogota, Colombia*

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INTRODUCTION

"Underdevelopment" is a term which applies to a variety of economic and sociological characteristics. In tangible terms underdevelopment is described by illiteracy and ignorance, social immobility, clear inequities in distribution of existing wealth, high incidence of sickness and disease, and, generally, political instability, among others.

It is our intent in this brief paper to describe a recent quantitative analysis directed to the improvement of the "welfare" of the residents of a developing region through the improvement in the transportation/storage system for a certain agricultural commodity. In particular, we are concerned with the problem of structuring the transportation/storage system in the savanna area around Bogota, Colombia, so as to minimize agricultural losses occurring between producers and consumers.**

Parenthetically we note that it is by no means clear that reduction in food losses will lead to an increase in per capita food consumption. In

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*This paper stems from an Interdisciplinary Seminar in International Development at the University of Southern California during calendar year 1967. A document describing this activity, "An Academic Experiment in Interdisciplinary Research: The USC Experience," has been prepared for presentation to an NSF-sponsored Workshop on Economics in Engineering at UCLA in the summer of 1968. The technical results of the seminar have been summarized in "A Systems Analysis of Farm-to-Market Food Losses in the Area of Bogota, Colombia." A limited number of each of these documents is available from the Department of Industrial and Systems Engineering, University of Southern California, Los Angeles, California 90007.

**The savanna is a plateau about 47 miles long and 24 miles wide at an elevation of about 8,000 feet in the Andes mountain chain. The city of Bogota is located on the savanna.

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the event that demand is inelastic, for example, a reduction in losses will lead to a price shift such that producers will in fact reduce the total amount of goods delivered so as to maximize revenue. In this study, however, we have assumed that reduction in food losses will in fact result in an increase in the food supply with a corresponding increase in per capita consumption.

It is also of interest to note here that an operationally meaningful definition of "food loss" is extremely difficult. Food may suffer nutritional degradation, aesthetic (marketability) degradation, physical loss, contamination, or bacterial spoilage. The relative importance of each mechanism varies primarily as a function of the type of good considered and the facilities involved. Although the effects of certain dietary deficiencies are known in a gross sense, the economic impact of these deficiencies are, at the margin, known only with general imprecision.

Because of time and data constraints, the following analysis focuses upon a single crop (potatoes) although the general concepts are appropriate for many other food products. Potatoes are one of the most important staples in the Colombian diet (data concerning this crop are readily available), potatoes sustain a significant amount of losses during the distribution and storage cycle, and the distribution/storage system for potatoes is in many cases the same as that used for other products. Potato production in areas around Bogota is illustrated in Figure 1.

SYSTEM MODEL

The agricultural marketing system consists of a sequence of physical processes performed by various organizational units. A tabular representation of the system attributes is listed in Table 1 along with additional details in the particular case of potato marketing. A variety of channels are utilized as the produce moves from producers to consumers but, while some produce moves directly from the grower to the consumer (about 10%), most are handled by middlemen and small retailers.

Collection stations are established by wholesalers for the purpose of consolidating limited deliveries provided by numerous, relatively small producers. Normally, wholesalers do not store more than a few weeks' supply. Potatoes are stored in the same sacks as those used for harvesting, and washing or inspection of the produce is generally nonexistent.

A lack of inspection and controls makes it difficult to estimate spoilage or wasted products between nodes of the system. Losses at the wholesaler,

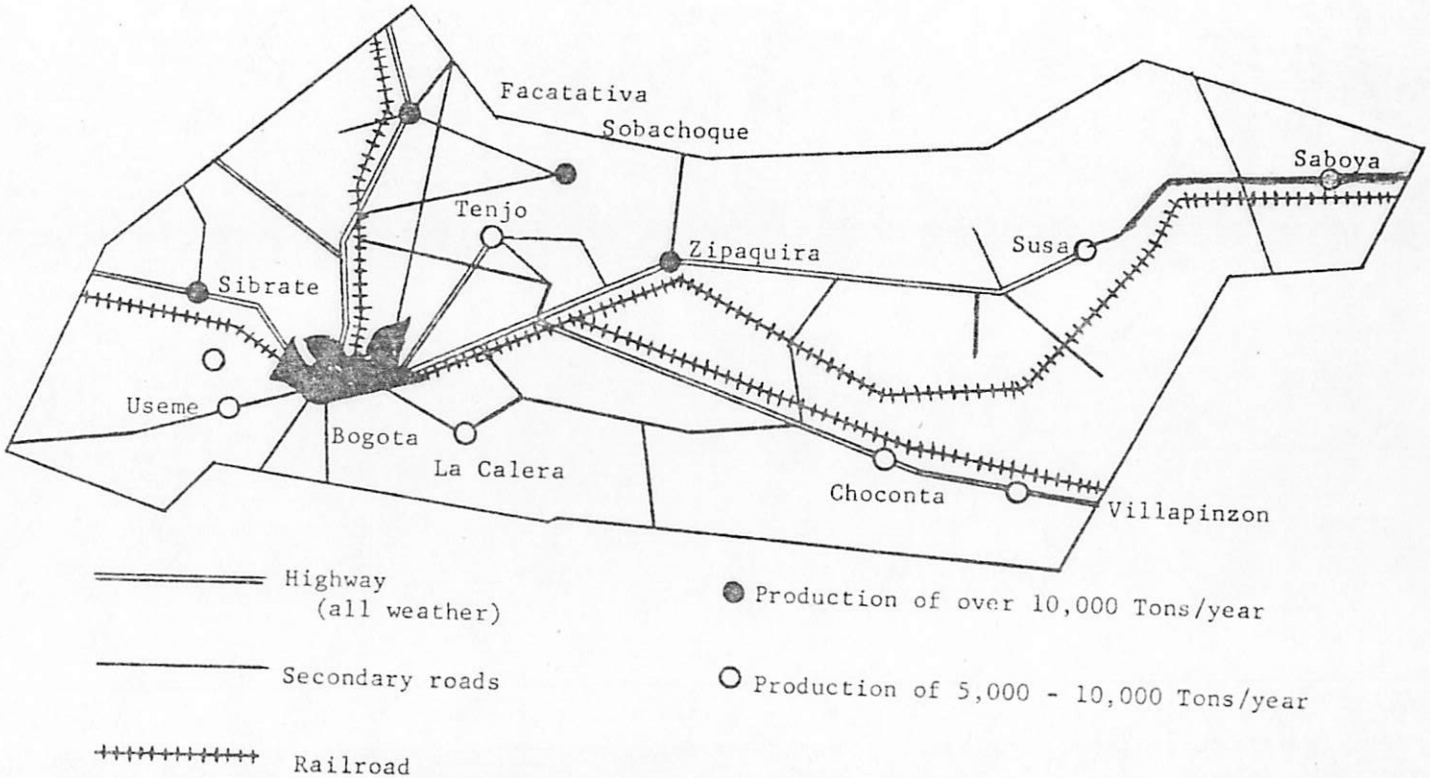


Figure 1

Potato Production Areas of the Bogota Savanna

Table 1

System Attributes

Main Area of Interest in This Study (Collection period through Retail sales time)

Time Interval	Physical Process	Organizational Unit	Example Organizational Structure (Potatoes)
Harvest period	Harvest	Farmer	Potato farmer
Collection period	Collection of crops into sufficient quantities for shipment	Middleman, wholesaler or farmer	Wholesale dealer and collector
Shipment time from farm to storage or wholesaler	Movement of products to storage or wholesaler	Trucker, middleman or farmer	Storage in silos (less than 5%)
Storage period	Storage in silos, grain elevators, etc.	Storage operators	Wholesaler (generally in the central marketplace
Wholesale sales time	Sales to retailer at central or rural market	Wholesaler, middleman or merchant at central market	
Retail sales time	Sales to consumer or other retailers at central market, retail market, supermarket	Retailer or middleman	Retailer (gets about 1/2 of goods from central plaza, rest from middlemen and farmers)
Consumer travel time, goods held by consumer and food preparation	Food preparation and consumption	Bogota consumer	Consumer (gets about 1/2 from central market, 1/3 from retail stores, and rest from middlemen and farmers)

for example, have been estimated by various government agencies to vary from one to sixteen percent, but interviews and other personal observations lead us to believe that a ten-percent loss appears to be a reasonable average. In like manner, we have selected what we believe to be reasonable estimates for average losses sustained at other steps in the marketing process. These are shown in Figure 2 in connection with a flow network for the distribution system.

POTATO MARKETING AS A QUEUEING SYSTEM

Of primary significance in analysis of the flow network is the queueing effect which occurs when the produce experiences delays at various nodes in the network, that is, a queue develops when produce arrives at a point of handling at a faster rate than it is processed. Thus, we may form an analogy between the statistical notion of a queue and the physical concept of goods in storage.

Physical damage, wastage, and degradation, occurring while produce is in the queue at a transfer point, are a function of such factors as time in process at the transfer point, the number of handlings, ambient temperature and humidity. In our simplified model, however, we assume that losses are a function only of time in each queue. This assumption is supported by experience with similar degradation processes.

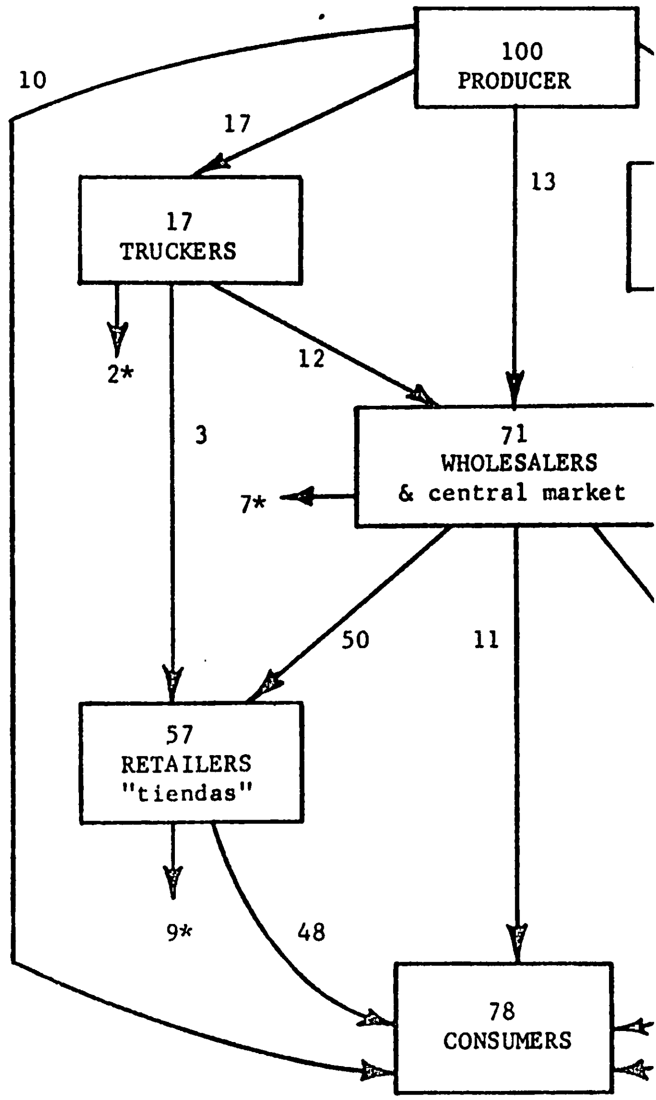
There is some experimental evidence to lead us to believe that this time-loss function is nonlinear and is of the general form indicated in Figure 3; losses increase initially at an increasing rate and then approach some maximum. Moreover, there is some reason to believe that the time in the system is less than "A" as shown in the graph, that is, the region of interest is such that the loss function is convex and can be approximated by:

$$\text{Losses} = K(t)^{\alpha} \qquad \text{(Eq.1)}$$

Thus, if K and α can be specified, losses may be reduced in a predictable manner by shortening the time produce spends in the system. For our purposes, we have assumed $\alpha = 2$ and time (t) is measured as time in the queue rather than time in the system. (Note: In the usual manner, time in the system represents the sum of time in service, i.e., in process, and time in the queue, i.e., waiting for service.)

The transfer functions at each node--that is, the functions specifying the amount of produce lost to the system at each node--has been determined

% LOS



Key: All numerical values are percentages o

* Indicates losses at a node.

Figure 2

Potato Marketing Channel

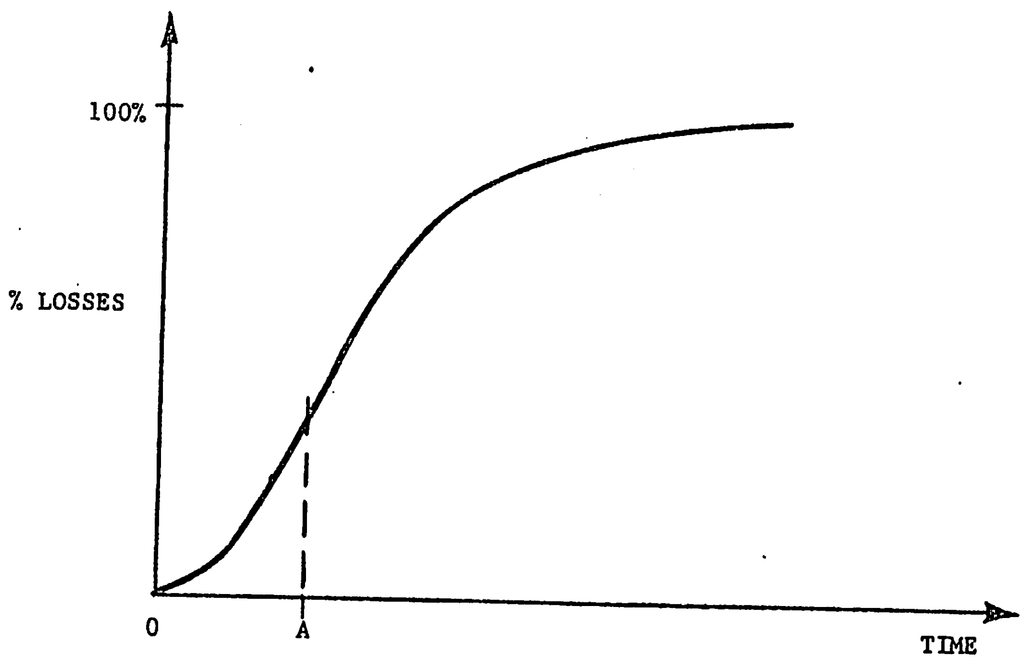


Figure 3

Generalized Time-Loss Function

in the following manner.

First, it is assumed that the service time (in process) at each node is a uniformly distributed random variable having a cumulative distribution function as illustrated in Figure 4. The extrema for the service times for the five nodes shown in Figure 1 have been estimated, based on empirical data as follows:

Node	Minimum	Maximum
Commission Agents	0.147 days	0.162 days
Truckers	0.494 "	0.546 "
Wholesalers	0.119 "	0.131 "
Retailers	0.687 "	0.758 "
Supermarkets	0.950 "	1.050 "

A "long-term storage" node has been added to the above to represent an intermediate facility capable of storing potatoes for relatively long periods of time so as to smooth out the differences between potato production cycles and relatively uniform consumption patterns. There is some reason to believe that the rate of processing (release from storage) at this node is inversely proportional to the amount in storage (Q_s) because of the supply-demand effects in the market place (see Figure 5). Large stocks tend to depress prices, leading to a reluctance on the part of sellers to release produce to the marketplace from long-term storage. Based upon certain empirical evidence then, long-term storage time is determined from:

$$D_s = C + 900/Q_s$$

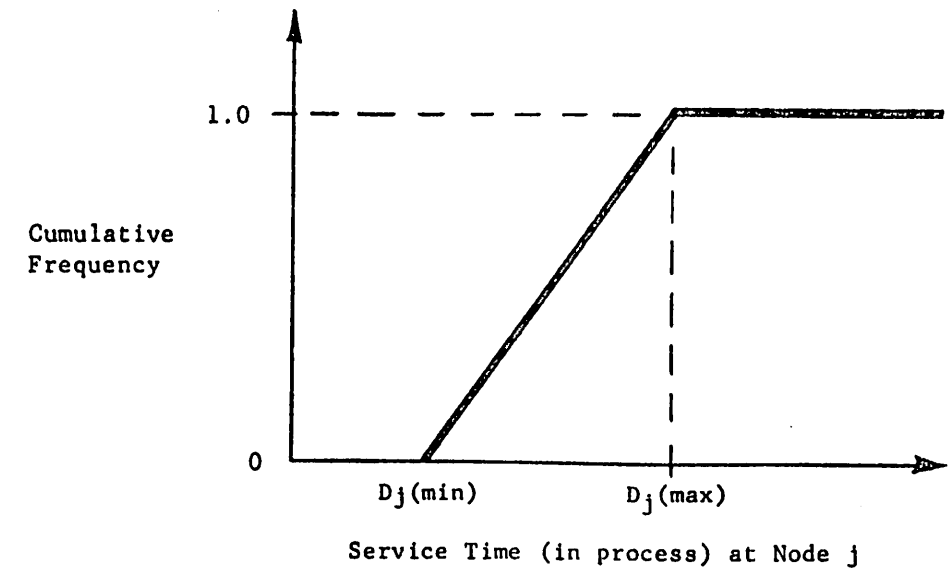
where the term C is a random variable uniformly distributed over the range 500 to 550.

Based upon the relationships as defined above, the total time at each node (T_j) is found by summing the time in service (D_j) and the time spent in the queue waiting for the service (Q_j). These values are determined by GPSS simulation.

The "transfers to loss" at each node are determined by combining our knowledge of average losses in the system (equation 1) and partial results of the simulation as described above. Consider the "Trucker" node, for example. Empirically, we know that 17 percent of production arrives at the node, 12 percent then flows to wholesalers, 3 percent to retailers, and 2 percent "to losses," i.e., is lost from the system because of spoilage, etc.

Figure 4

Cumulative Distribution Function for D_j



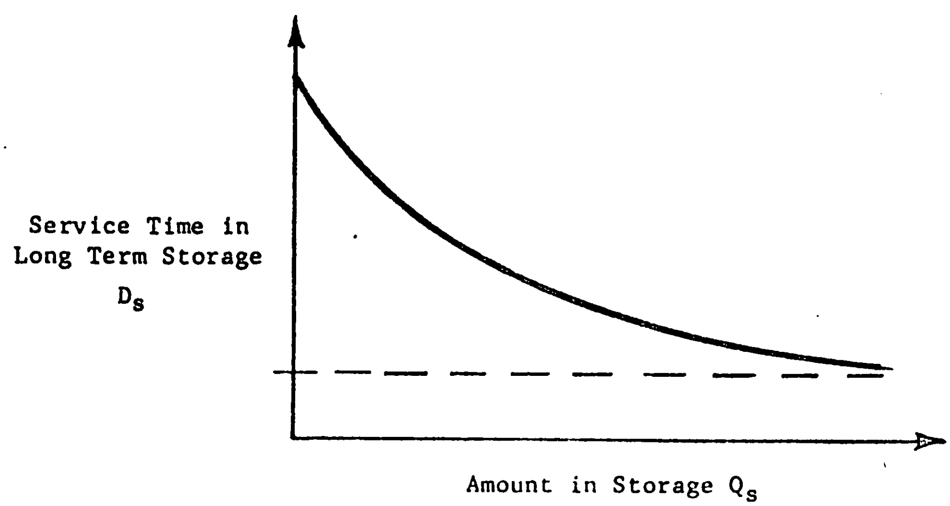


Figure 5

Service Time at Long Term Storage as a Function of Amount in Storage

Thus the average loss (L_t) at the node is 2/17 of the amount entering the node, and , by equation 1:

$$\overline{L}_t = k\overline{T}_t^{\,2} \tag{2}$$

Here, $\overline{T}_t$ is the average time spent at the "Trucker" node and is a result of the simulation process indicated earlier. In this example, $\overline{T}_t = 0.520$, and thus the value of the coefficient k is:

$$\begin{aligned} K_t &= \overline{L}_t/\overline{T}_t^{\,2} \\ &= (2/17)/(0.520)^2 \\ &= 0.435 \end{aligned}$$

In like manner, the loss function coefficients for the remaining nodes have been determined to be:

Commission Agents	$K_c = 2.17$
Wholesalers	$K_w = 6.32$
Retailers	$K_r = 0.302$
Supermarkets	$K_m = 0.111$

The transfer functions for the marketing system model are summarized in Table 2. (It will be noted that an artificial "transfer to loss" node has been added to serve as a balancing sink. Also, note that the table reflects the operating assumption that "long-term storage" receives inputs directly from producers; outputs are directed to truckers, commission agents, and wholesalers.) Cell values indicate the proportions of the input from node i destined for node j, where L_j represents the portion of the total amount produced but lost at node j. To illustrate, again consider the "truckers" node. The portion of total production entering that node is 17%, of which 12% is destined for wholesalers, 3% goes directly to retailers, and 2% is lost. Thus $(1-L_t)$ is the percentage not lost and, of this amount, 12/15 goes to wholesalers and 3/15 to retailers, or 0.8 and 0.2 respectively.

With completion of the table of transfer functions, we may now determine the total amount of potatoes produced but which are lost in the system.

SIMULATION AND ANALYSIS

Several variations of the basic model have been examined as a computer

Table 2

Transfer Functions for the Marketing System Model

To

From	Prod.	Long Term Storage	Trucker	Comm. Agent	Wholesalers	Retail	Supermarkets	Loss	Consumer
Producer	0	0.05	0.165	0.57	0.12	0	0	0	0.095
Long term storage	0	0	.17	.60	.13	0	0	0	.10
Truckers	0	0	0	0	$.8(1-L_t)$	$.2(1-L_t)$	0	L_t	0
Commission agents	0	0	0	0	$.81(1-L_c)$	$.07(1-L_c)$	$.1(1-L_c)$	L_c	$.02(1-L_c)$
Wholesalers	0	0	0	0	0	$.78(1-L_w)$	$.05(1-L_w)$	L_w	$.17(1-L_w)$
Retailers	0	0	0	0	0	0	0	L_r	$1-L_r$
Supermarkets	0	0	0	0	0	0	0	L_s	$1-L_s$
Losses	0	0	0	0	0	0	0	1.0	0
Consumers	0	0	0	0	0	0	0	0	1.0

simulation.* In the first simulation, the model assumes a bi-modal input distribution to the network (representing Colombia's two-season potato crop) as well as the transfer function as summarized in Table 2. In the second simulation a uniform production distribution is assumed. Outputs for two simulations are shown in Tables 3 and 4.

Variations in delay times or transfer functions will change system and queue times which will, in turn, create new loss values since loss functions are sensitive to queue lengths. For example, if the truckers delivered their cargoes at a more rapid rate, the delays (and therefore the queues) would be shortened and the resulting losses would be reduced. Also, the effects on losses of a more constant production function or a more stable production cycle can be determined by comparing Tables 3 and 4. The maximum and average queue lengths at each transfer point are measured in the simulation program so as to provide information about storage requirements at various steps throughout the marketing system.

Three alternative plans for reducing food losses were evaluated: (1) increasing the capacity of storage facilities, (2) introduction of food processing as an intermediate step between producers and consumers, (3) improved farm-to-market transportation.

Increased storage facilities reduce loss rates in the queues, resulting in a reduction in the α term appearing as the exponent in equation 1, and they also tend to level out the cyclic changes in the system by holding back produce during peak periods. Storage at the early points in the network acts to flatten out the input function to subsequent nodes which in turn reduces the length of the queues. Long queues build up to very high levels when inputs are at a peak resulting in greater losses.

Food processing also tends to reduce the loss rate and permits longer storage in the queues. It involves many additional considerations, of course, but some of its effects may be measured by the model. Improved transportation on the other hand acts to reduce delays in the network, thereby leading to shorten reduction in losses.

The model and simulation procedure described in this paper have been useful in a cost-benefit analysis of the above alternatives. Although beyond the scope of this paper, it may be of interest to note that the introduction

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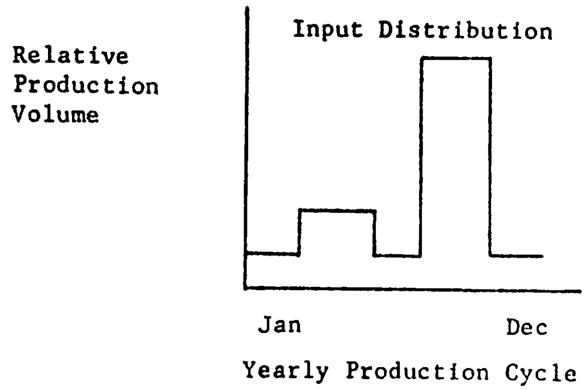
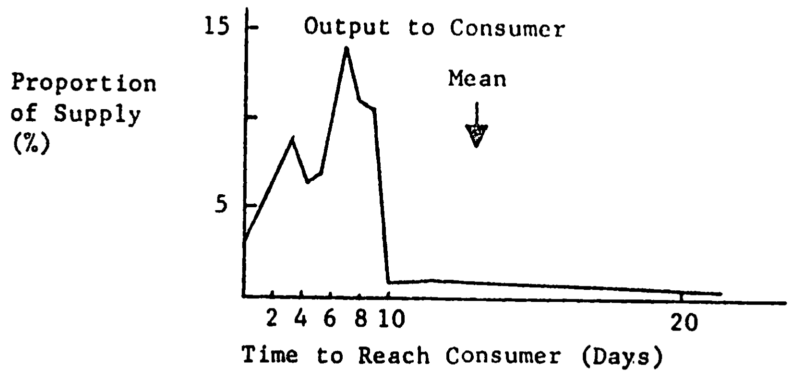
*The program, written in GPSS III, is available from the authors.

Table 3

Sample Analysis

Simulation 1: Bimodal Production





Losses at:

Truckers	10%
Commission Agents	5%
Wholesalers	10%
Retailers	15%
Supermarkets	5%

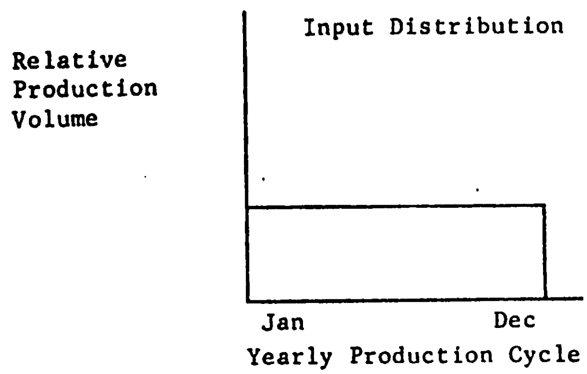
Total Losses in the System = 21%

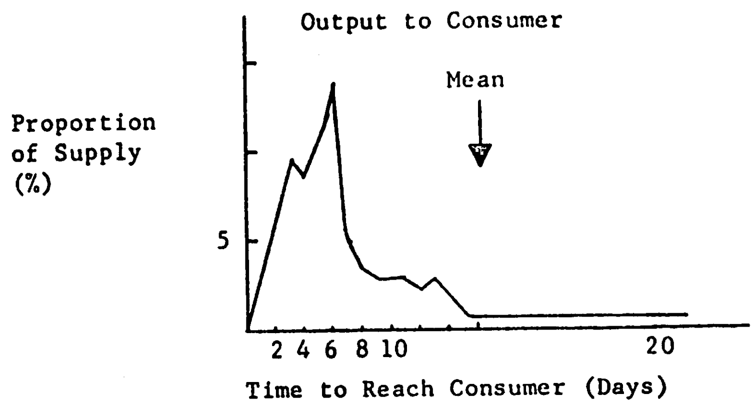
	Average	Maximum
Time from farm to consumer	10 days	53 days
Time at the retailer	3 days	18 days
Time at the wholesaler	22 days	31 days

Table 4

Sample Analysis

Simulation 2: Constant Production





Losses at:

Truckers	8%
Commission Agents	4%
Wholesalers	9%
Retailers	15%
Supermarkets	5%

Total Losses in the System = 18%

	Average	Maximum
Time from the farm to the consumer	8 days	36 days
Time at the retailer	3 days	12 days
Time at the wholesaler	8 days	16 days

of expanded long-term storage facilities to 110,000 tons would result in a total system loss of about 10%; the loss level with only minimal storage facilities, 12,700 tons in 1967, was approximately 21%. Converting these losses to an equivalent dollar value based on market price, the resulting reduction in food losses would yield equivalent annual benefit of $1,462,000; associated equivalent annual costs would be $491,000.

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