A STOCHASTIC SIMULATION MODEL FOR A TOMATO PROCESSING PLANT IN SOUTHEASTERN OKLAHOMA

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CHAPTER I

INTRODUCTION

Tomatoes for processing have been recognized as a principal vegetable crop produced in the United States for several years. Over the period 1970 through 1987 processing tomato production grew at an annual average rate of about two percent as the output rose from 5.5 million tons in 1970 to 7.6 million tons in 1987 and accounted for about 60 percent of total processing vegetables excluding potatoes. The total value of the crop increased from $171.9 million in 1970 to $448.6 million in 1987 making it the second most valuable vegetable crop following potatoes. Processed tomato pack which consists of six major canned tomato products (canned whole tomatoes, tomato paste, tomato juice, tomato catsup, and chili tomato sauce) has shown an upward trend to meet the rising demand for tomato products. Carry over stocks have also risen. Per capita consumption of canned tomatoes which constitute the bulk of the canning industry, has expanded from 53.8 pounds in 1970 to 64.0 pounds in 1987 and scored its highest in 1984 at 68.4 pounds (farm weight basis). Table I shows the trends in total output, total value, and per capita consumption for processing tomatoes and the four major processing vegetables (tomatoes, green peas, sweet corn, and snap beans) for the United States, 1970-1987.

The growth in tomato processing industry is largely attributed to the high demand for processed tomato products which has been linked to the expansion of fast food restaurants along with the changes in the American life styles

Table I. Production, Value, and Per Capita Consumption for Processing Tomatoes and the Four Major Processing Vegetables for the U.S., 1970-1987.

	Processing Tomatoes			Major Processing Vegetables		
Year	Production	Value	Per Capita Consumption	Production	Value	Per Capita Consumption
	Tons	$1,000	Lbs.	Tons	$1,000	Lbs.
1970	5,508,950	171,857	53.81	8,456,850	324,782	80.53
1971	5,515,550	195,738	59.81	8,694,050	357,459	90.01
1972	5,803,700	204,366	60.66	9,052,650	368,626	90.88
1973	5,934,550	249,085	59.60	9,374,300	451,019	91.88
1974	7,019,850	453,022	61.32	10,410,800	795,148	91.96
1975	8,503,750	537,452	61.93	12,132,800	892,379	90.12
1976	6,471,750	375,407	65.63	9,806,750	666,487	95.81
1977	7,779,150	498,372	62.75	11,319,750	814,454	94.30
1978	6,367,700	408,950	58.84	4,480,100	729,878	89.96
1979	7,329,510	495,476	64.24	11,175,930	868,874	96.73
1980	6,210,590	378,853	63.59	9,557,070	706,103	91.27
1981	5,716,130	385,632	59.30	9,221,520	746,130	88.48
1982	7,298,990	522,422	60.06	11,179,590	909,738	88.72
1983	7,024,800	480,926	60.83	10,270,050	800,600	87.80
1984	7,681,160	517,488	68.40	11,394,780	911,219	99.48
1985	7,177,130	475,709	63.07	11,096,980	900,295	94.22
1986	7,393,290	472,538	63.40	10,977,010	814,402	93.89
1987	7,596,580	448,565	NA	11,580,620	825,597	NA

NA: Not Available

Source: United States Department of Agriculture, Economic Research Services. Different Issues 1986-1988.

(United States Department of Agriculture, Economic Research Services, Feb. 1987; and Brandt and French, 1981).

California became the major producer of tomatoes in the United States when its share of the supply expanded from 25 percent in the early fifty's to eighty-eight percent in 1986 as production location shifted from the east (New Jersey, Pennsylvania, New York, and Delaware Peninsula) and the Midwest (Illinois, Indiana, and Ohio) due to the more favorable growing conditions in California.

The rising demand for tomato products has propelled the growth of the tomato industry and attracted other states to enter the industry as they seek more profitable crops and diversified agricultural production.

The Problem

In a study of twenty-four counties in southeastern Oklahoma, Badger and Williams (1982) indicate that some producers in the region are considering alternative crop enterprises, especially fruits and vegetables, as the chances of improving incomes from traditional cattle and grain crops had declined. Their survey reveals some problems that farmers face, including inadequate markets and lack of agribusiness firms which they considered to be crucial in improving agriculture and relieving cash flow problems in the agricultural sector by providing off-farm employment opportunities.

Vegetable production in the area has been encouraged by the findings of the research conducted by the Horticulture and Landscape Department at Oklahoma State University. Vegetable Trail Reports indicate that climatic conditions are suitable for vegetable production (Oklahoma State University, 1987). With the increased interest in vegetable growing, questions about the possibilities of establishing a vegetable processing industry arise. Tomato, which has been processed in Oklahoma, is being considered as a potential crop for processing due to the higher returns associated with the crop. However, changes in temperatures, recognized by McCraw, et al., 1987, University of California, 1985, and Logan and Boyland, 1983 as the most important factor influencing tomato growth and yield, can cause high variability in tomato yields. This variability can have a large impact on the continuous flow of raw tomatoes required by the processing facility and hence processing operation costs which impact the successful operation of the processing firm.

Objectives

The overall objective of this study is to provide tools for analyzing the costs of processing tomatoes in Oklahoma in a stochastic business environment.

Specific objectives include:

1. Constructing an annual planning simulation model for a tomato processing firm operating under an environment of stochastic temperatures and yields.
2. Finding the least cost operation plan to meet an assumed combination of processed tomato products given that tomato yields and processing operation costs are stochastic.
3. Estimate total revenues and total costs of the enterprise.
4. Analyze the impact of the stochastic processing costs on the firm's expected profits.

Study Area

Selection of a study area depends on the source from which the problem arises, the need and potential impact of the study for the area and the availability of resources and information about the climatic condition and business environment surrounding the enterprise under consideration.

Haskell, Hughes, Pittsburg, and Le Flore counties included in the study by Williams and Badger, and McIntosh, Muskogee, and Sequoyah counties of east central Oklahoma (striped area in Figure 1) are chosen as the study area due to their location along the Arkansas and Canadian Rivers. The area also possesses the potential for growing vegetables due to suitable climatic conditions.

Agricultural Resources in the Study Area

According to the 1982 Census of Agriculture, the land in farms for the seven counties of the region was 2,311,600 acres comprising about 60 percent of the total land area of the counties. In 1978, the number of farms in the region was 7,577 with an average farm size of 315 acres, and in 1982 the number of farms increased to 7,868 farms and the average farm size declined to 296.7 acres. Total cropland was estimated at about 822,200 acres or about 36.7 percent of the land in farms. Of the acres used for cropland nearly 51 percent was in pasture and rangeland. And of the acres in woodland, about 74 percent was used for pasture (Table II).

The total market value of the agricultural products sold from these farms in 1982 was about $114.8 million, an increase of $3.9 million from 1978. Most of the increase came in grain crop sales. Crop farms accounted for 22.27 percent of the total sales in 1982 and livestock, poultry, and poultry products contributed 77.73 percent. The majority of farm income in 1982 came from the sales of cattle and calves which accounted for about 60 percent of total farm sales followed by grain crops (wheat, corn, soybean, sorghum, and oats) with 11.17

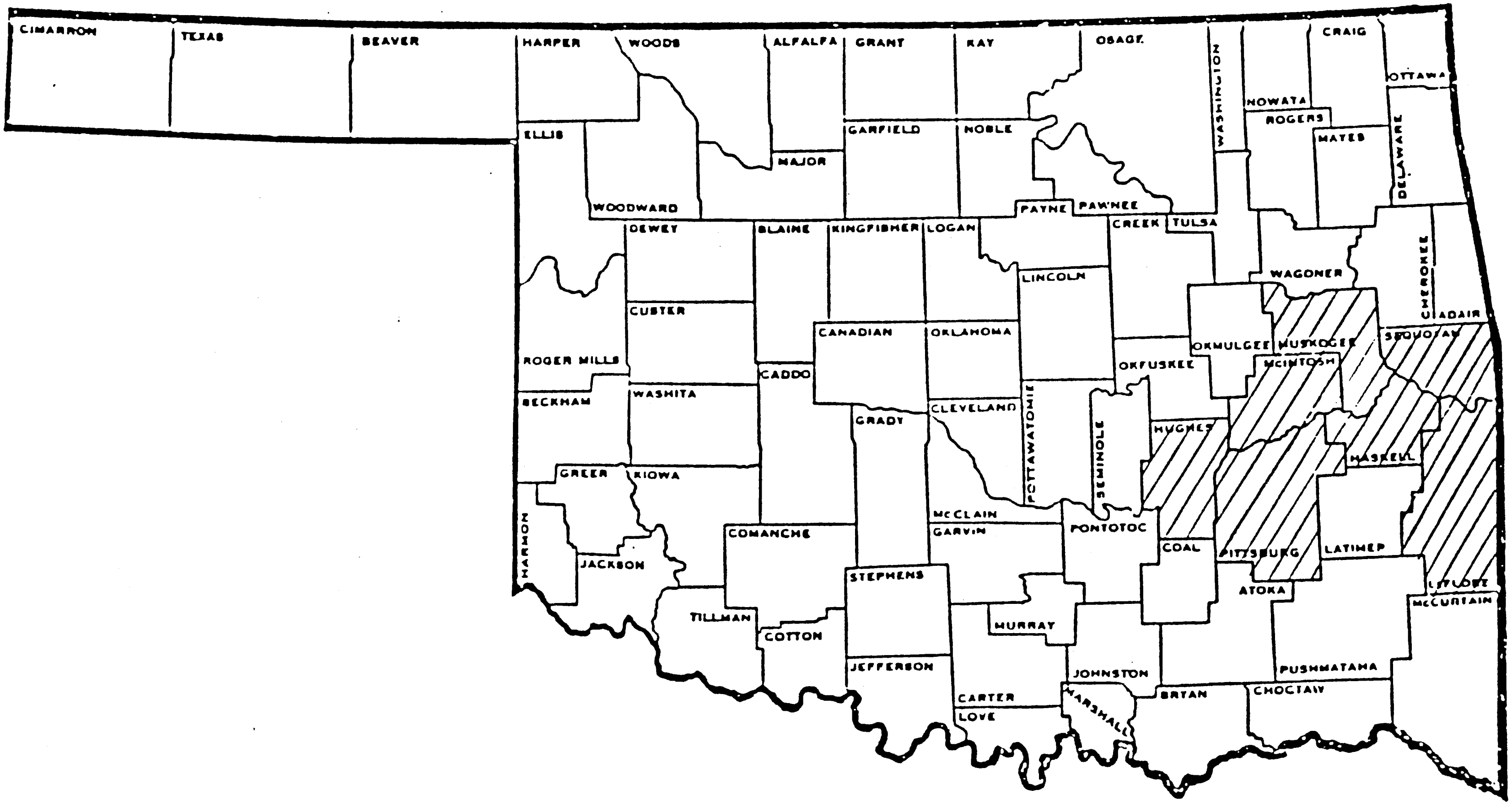

Figure 1. Study Area.

Table II. Farms, Land in Farms, and Land Use for the Study Region 1978 and 1982.

Item	Units	1978	1982	% Change
Total Farms	Number	7,577	7,868	3.84
Land in Farms	1,000 Acs.	2,395.3	2,311.6	-3.50
Average Size of farms	Acres	315.0	296.7	-5.81
Approximate Land Area	1,000 Acs.	4,033.6	4,033.6	0.00
Percent of Land Area in Farms	Percent	59.4	57.3	
Land in Farms According to Use				
Total Cropland	1,000 Acs.	822.2	849.4	3.31
Harvested	1,000 Acs.	357.1	365.4	2.32
Pastured	1,000 Acs.	407.9	434.6	6.55
Other	1,000 Acs.	57.1	49.3	-10.51
Total Woodland	1,000 Acs.	416.9	388.0	-6.93
Pastured	1,000 Acs.	306.7	296.0	-3.49
Not Pastured	1,000 Acs.	110.2	91.9	-16.60
Other Land	1,000 Acs.	1,111.6	1,074.3	-3.36

Source: United States Department of Commerce, 1982 Census of Agriculture.

percent (Table III). The market value of growing vegetables, sweet corn, and melons sold was reported as $1.6 million for 87 farms out of 91 farms which grew these crops. The total acres devoted to vegetables in the region was 4,413 in 1982 comprising about 36 percent of the state's total. Poultry and poultry products, dairy products, hogs and pigs farm sales reported in the census contributed about 6.77, 6.48, 1.37 percent of the total farm sales, respectively.

This chapter provided a brief introduction on the economic performance of processing tomatoes, and introduced the problem statement, objectives, study area, and summarized statistics of the agricultural resources in the area. The next chapter presents selected topics from a review of the literature on risk and risk analysis, and some of the work contributing to investment analyses under conditions of risk and uncertainty.

Table III. Type of Farm by Number and Value of Agricultural Products Sold, Study Region 1978 and 1982.

Item	1978 No. Farms	1978 Value	1982 No. Farms	1982 Value
		$1,000		$1,000
CROPS	1,710	21,686	1,496	25,560
Grains	783	9,330	713	12,828
Cotton & Cotton Seed	8	(D)	3	(D)
Field Seeds, Hay Forage & Silage	619	2,677	835	3,055
Vegetables, Sweet Corn & Melon	99	(D)	91	(D)
Fruits, Nuts & Berries	76	(D)	41	(D)
Nursery & Greenhouse Products	33	(D)	51	(D)
Other Crops	243	4,266	177	4,142
LIVESTOCK, POULTRY & THEIR PRODUCTS	6,444	89,222	6,884	89,237
Poultry & Poultry Products	239	(D)	233	(D)
Dairy Products	140	(D)	114	(D)
Cattle & Calves	6,700	67,338	6,622	68,197
Hogs & Pigs	560	1,890	371	1,572
Sheep, Lambs & Wool	64	(D)	128	237
Other	420	(D)	411	(D)

(D): Withheld to avoid disclosing data for individual farms in some counties.

Source: United States Department of Commerce, 1982 Census of Agriculture.

CHAPTER II

BACKGROUND AND LITERATURE REVIEW

Agricultural business engulfs more risk generating factors than most other businesses. Weather, diseases, insect infestations, price variations, and yield variations are examples of factors which make an agricultural business's future vulnerable to risk.

Identifying the sources of risk helps in developing guidelines for the selection of effective methods of managing risk in agriculture. Barry and Baker (1984) classified risk for agricultural business firms into two distinctive types, business risk and financial risk. Both types of risks combine to determine total risk for the firms. Financial risk arises from the financial claims on the firms, while business risk refers to the variability of returns to the firm's risky assets. Sonka and Patrick (1984) described five major sources of business risk: 1) production or technical risk caused by unpredictable changes in environmental factors, diseases, and pests which leads to increased variabilities in yields; 2) price or market risk caused by fluctuations in both input and output prices, since costs incurred at later stages of the production process of agricultural commodities are uncertain when the process begins; 3) government policies, regulations, and unanticipated new laws which add to the complexity of the business environment; 4) rapid technological innovations which require the decision maker to decide whether or not to adopt the new technology as a precautionary measure against the risk of inefficiency or obsolescence; and 5) the human source where a loss of management personnel or an important employee may increase risk if a replacement for the lost personnel was unavailable. The focus of this study will be on the first two components of business risk.

Tomatoes are grown when the season is warm, temperatures below or above a certain range will not permit economical yields. Frosts, diseases, and other environmental factors influence tomato yields and can generate great fluctuations on both the quality and quantity of tomatoes produced. Certain characteristics of the tomato fruits which are required for processing may be reduced or even destroyed. Yield variability caused by uncertain weather conditions can have a large impact on the costs of production and the costs of the firm's processing operations. When the weather is favorable, yields will be high and the firm may have to operate at full capacity for a period of time. On the other hand, when bad weather occurs, yields will be low and the processing operations slow down or may even temporarily stop when the weather is worse and non-economical yields are produced. The uncertain business environment created by unpredictable changes in weather conditions can have a large impact on the successful operation of the processing plant. In this application, only the effect of uncertainties created by changes in temperature are considered.

Probability

Probabilities provide a means by which decision makers measure the likelihood or the chance of the occurrence of particular events under uncertain circumstances. The application of probability in the decision making process to predict future outcomes goes back to the seventeenth century and the concept of probability was established long before that. There are two important types of probabilities: subjective probability and objective probability. The latter refers to the case when probabilities are interpreted in a frequency concept, the measure of relative frequency of occurrences of an event in a large (infinite) number of observations. The use of such probability assumes that the distribution of realized outcomes is unchanged and the anticipated occurrences or distribution will be the same in the future. The former term refers to the degree of belief or strength of conviction of an individual for a particular proposition (Dillon, 1971). Subjective and objective probabilities are used to construct probabilistic distributions for particular variables such as prices, yields, and returns from which estimates of the variabilities of outcomes can be derived. Dillon argued that deriving objective frequencies based on finite historical data for future probabilities involves the subjective presumption that the distribution of events has not changed and hence subjective probability is being used.

Subjective Probability Assessment

Specifying a probability distribution that describes the stochastic nature of random variables which influence the decision process is necessary to analyze the impact of such variables on the type of investment being studied. Several techniques have been proposed in the literature for eliciting subjective probabilities. There are two distinctive methods as classified by Bessler (1984). The first is a motivating method which has an explicit payoff in the form of a reward or a penalty to the assessor based on his assessment of the outcome of the uncertain event. This method is based on the assumption that the assessor maximizes the expected payoff in a gambling situation. A scoring rule is a means by which the assessor is rewarded or penalized to keep the assessments accurate and report his/her true beliefs about the uncertain variable such that they are equal to the stated probabilities. The second is a nonmotivating method which does not involve a payoff or require the assessor to state the probabilities directly and is based on the finding of equally likely probabilities for the random variable in question. The judgmental fractile procedure (Raiffa, 1968; Anderson et al., 1977; and Bessler, 1984) is an example of this method. The fractile, defined as the value of a random variable x for which the probability of x is less than or equal to a specific value, is constructed using a hypothetical reference gamble.

The assessor's knowledge and understanding of the assessment procedure seems to govern the outcome consistency between different methods (Hogarth, 1975). The choice of an adequate method to use is still dubious. Sprow (1967) argues that the distributions obtained from direct elicitation have little evidence to support their accuracy and the method or distribution that possesses certain characteristics and can be specified by it's economic estimates should be used. Nelson et al., (1978) suggest four different procedures for the elicitation of subjective probabilities; the cumulative distribution, the conviction weight, direct elicitation, and the triangular distribution procedure. Keeping with Sprow's viewpoint they argue that the triangular distribution approach is better understood and can be identified by the maximum, most likely, and the minimum values of a random variable. McSweeny et al., (1987) proposes a mean square forecast error as an appropriate measure of uncertainty and suggest that researcher's should use variance-covariance analysis until substantial evidence exists to support which empirical approach is most accurate in reflecting the subjective probabilities.

Methods of Risk Analysis

Developments of various methods of mathematical programming techniques have provided a powerful set of tools for agricultural specialists to analyze the firm performance under risk. Attempts have been made to incorporate risk into agricultural problem analysis and programming techniques and analytical innovation were extended to reflect the stochastic nature of some variables influencing decision making in agriculture. Incorporation of risk into a whole farm planning model was first prepared by Fruend (1955) by extending the conventional linear programming problem formulation in conjunction with the expected utility model into a quadratic problem to find an optimal combination of crops for a representative farm.

Quadratic risk programming has been widely accepted as a method of risk analysis and enjoyed extensive applications in agriculture. Computational problems that accompany the use of quadratic programming algorithms have provided incentives for the development of other programming techniques like Minimization of Total Absolute Deviations (MOTAD), separable linear programming techniques developed by Thomas, et al. (1972) which uses a linearized version of the objective function of quadratic programming model, and marginal risk constrained model proposed by Chen and Baker (1974) which can be used to approximate the E-V frontier in a multi-stage linear programming algorithm. These mathematical programming techniques develop single valued estimates for a number of planning alternatives from which the decision maker is able to choose according to his subjective preferences. In a sequential stochastic environment such as agriculture, these techniques provides the decision maker with a crude representation of events occurring in the real world (Cassidy et al., 1970 and Anderson et al., 1977).

Simulation Analyses

Simulation is an alternative method which has met great acceptance as a superior means to analyze agriculture investments under uncertain circumstances. It is a flexible procedure which allows the incorporation of complex stochastic variables more easily and less restrictive than most other stochastic models (Anderson, 1974).

Simulation in a broad definition is simply to simulate, feign, or approximate a real system via models. Naylor et al., (1968) describe simulation as a technique that involves setting up a model of a real situation and then performing experiments on it. Anderson et al., (1977) defines simulation as mimicry of the behavior of a modeled system over time by numerical exploration of a symbolic model. The structure of simulation models is not bounded by a specific design like linear or quadratic risk programming. Optimization criteria are not the focal point in simulation, but the technique accommodates linear or non-linear objective functions and/or a set of mathematical equations representing a certain system to be simulated over a single or a multiperiod of time, stochastically or deterministically.

Law and Kelton (1982) classify simulation models according to their representation of time and the state variables. A static model represents the real system at a particular point of time, and a dynamic model represents the real system over time. A deterministic simulation model does not involve random variables as opposed to a stochastic model. A continuous simulation model accounts for the state variables as they change continuously over time, and a discrete model accounts for the variables that change over a finite number in time.

Logan (1984) developed an annual planning simulation model for a tomato processing plant in California. The design of the model is based on operating specification for an existing tomato processing firm with a specified number of processing lines and a fixed combinations of possible final products. The model can generate weekly processing operation schedules and costs over the processing season. Given the projected arrival of the raw product for each week, the model determines the quantity to be processed, the number of days to be worked, and selects the minimum cost combination of processing lines among several feasible cost alternatives used to process this quantity. The model is also designed to predict planting dates using the concept of heat unit given the starting date of the processing operations.

Starbird and Ghiassi (1986) developed a simulation model for a proposed tomato processing firm to evaluate the technological feasibility of meeting the pack plan requirements and the effect of various production scheduling alternatives on the plant profitability.

Monte Carlo Simulation

Monte Carlo simulation is an approach used in risk analysis and often connected to simulation analysis. The procedure uses probability distributions that describe the stochastic behavior of random variables to generate random samples in a repeated process which are then used to estimate the probability distribution of the key output variables in a simulation model.

Cassidy et al., (1970) developed and applied a simulation model for investment analysis of pasture improvement strategies. Triangular distributions were employed to generate stochastic random variables using Monte Carlo methods. Cumulative distributions of outcomes were obtained from several runs of the model over time and the results were compared with results obtained by others from a mathematical programming model. They concluded that the simulation technique was more appropriate for investment analysis.

Hardin (1978) developed a simulation model to analyze farm investments feasibility under stochastic environment. The model utilizes trended and correlated prices and yields that are either normally or triangularly distributed.

Richardson and Nixon (1986) constructed a simulation model for a representative farm called "The Farm Level Income and Policy Simulation Model" (FLIPSIM). The model is capable of simulating alternative farm policies, marketing strategies, farm structure, farm management strategies, and other important issues in farm planning. The model is also capable of drawing random variables from independent or multivariate normal, empirical, and/or triangular probability distributions.

This chapter highlighted the foundations of risk and risk analyses in agriculture and the importance of risk in the decision making process. Some alternative programming techniques used to analyze risk were also highlighted emphasizing simulation techniques and Monte Carlo methods. The next chapter introduces the methodology and model development process followed in this study to develop the stochastic simulation model for a processing tomato cannery.

CHAPTER III

METHODOLOGY AND MODEL DEVELOPMENT

The first objective of this study is to develop a stochastic simulation planning model projecting the costs of processing tomatoes in Oklahoma. The model is then used to analyze the effect of stochastic temperatures on tomato yields which in turn influence processing plant operation and costs.

Tomato processing requires that the manager's knowledge goes beyond plant operations to include tomato growing operations. Careful study of the environmental factors affecting tomato plant growth, and the relationship between growing and processing tomatoes allow the manager to make better planning schemes for the upcoming processing season.

The grower-processor relationship can be illustrated by the flow chart shown in Figure 2 which represents a simplified version of a grower-processor subsystem of the tomato processing industry. This study will focus on the processing subsystem.

Processing Firm Operations

In general, most tomato processing plants perform the same functions with slight differences in the type of final products produced and production capacities.

The processing tomato firm's operations consist of several common steps as defined by Logan (1984). The first step, after unloading the raw product is

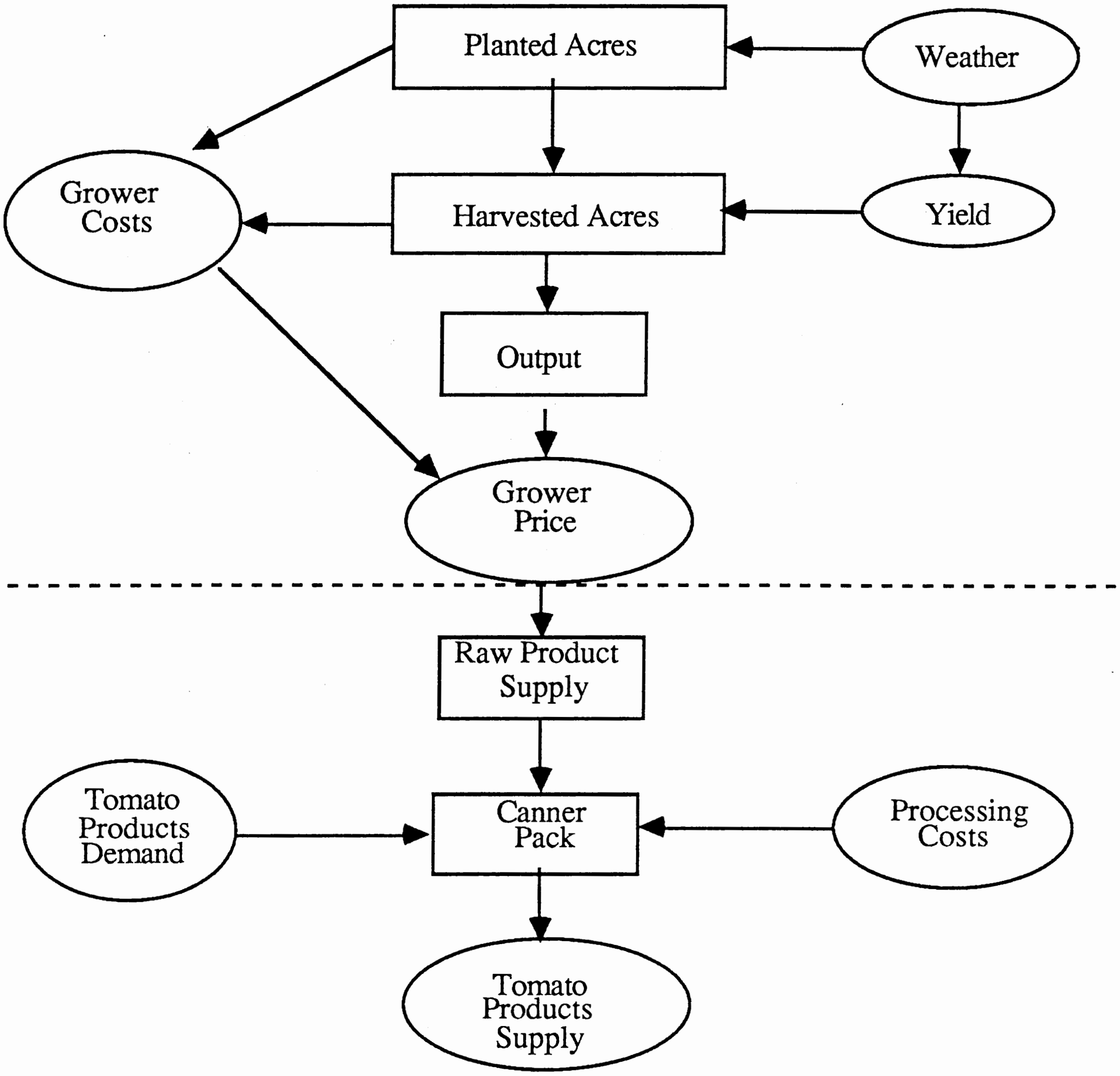

Figure 2. A Flow Chart for A Tomato Grower-Processor Subsystem

washing and distributing raw products to either whole tomato processing or processed tomato product processing. Tomatoes are then inspected and sorted for certain qualification standards for whole or processed products. Those meeting required standards are routed to their processing units and those failing to meet the standards are disposed. Tomatoes allocated to processed products are crushed, evaporated, manufactured into certain products and sent to the appropriate units. Tomatoes allocated to whole tomato processing, after undergoing further inspection for color and texture, are routed to processing lines for whole tomato canning, if qualified, or to processed tomato product lines, if not qualified. In the final step, whole and processed canned tomatoes are cooked, and the cans are inspected, cooled, and routed to the warehouses.

The Processing Unit

The processing unit consists of twelve independent canning lines which can produce whole peeled tomatoes, paste, and sauce with a rated capacity of 185 tons per hour when all the lines are producing different kinds of products. The twelve lines are divided into three groups and numbered from 1 through 12 to reflect the priority by which they are used in the processing operation. The first group consists of lines 1 through 7 which can produce only whole peeled tomatoes in No. 303 cans for the first three lines, in No. 10 cans for lines 4 and 5, and in No. 2-1/2 can for lines 6 and 7. These seven lines have a combined capacity of 61 tons per hour. The second group consists of lines 9, 10, and 11 which can produce only paste in 6 oz, 12 oz, and 6 oz cans, respectively. The third group consists of lines 8 and 12 which can produce only sauce in No. 10 and 2-1/2 cans, respectively, until the season's output requirements for sauce are met, after which they can be used to produce paste in the same can size.

The combined rated capacity of lines 8 through 12 is 129 tons per hour when they are used to produce paste only and 124 tons per hour when paste and sauce are produced. The capacity of the processing unit increases from 185 to 189 tons per hour when all the lines are producing whole tomatoes and paste. For computation purposes, lines 8 through 12 are renumbered as lines 13 through 17 when they are used to produce paste only.

Processing Costs

One of the main objectives of this study is to find the least cost operation plan to meet an assumed combination of final products given the weekly stochastic flow of raw products. Processing costs incurred depend on the amount of raw product processed and the time used to process the final products. Given that the firm allocates a certain amount of raw product for different types of final products, the firm may have to work different shifts with various numbers of lines each week in order to meet the final product requirements. Therefore, processing costs (variable) for any given processing line are a function of the costs incurred per one shift and the number of shifts worked on that line, and the total weekly variable processing costs (TVC) is the sum of those costs for the lines used for the week which can be stated as:

$$TVC = \sum_i N_i C_i$$

where N_i is the number of shifts worked by line i and C_i is the variable costs per shift of operating line i.

The Simulation Model

A stochastic simulation model based on Logan's model is developed and will be used to analyze the effect of stochastic tomato yields caused by unpredictable temperature variation on the costs of processing tomatoes.

The model is designed to develop weekly operating schedules and costs for a tomato processing plant and select the minimum cost combination way of producing a specific mix of final products. The model is also designed to generate random tomato yields and predicts planting dates for the raw products based on the heating unit concept.

The basic structure of the model is depicted by the flow chart of Figure 3, and is composed of the following basic components:

Component 1: The model starts by reading and calculating the input data which does not change during the simulation process: acreages used to produce the raw product, the percentage of the annual quantities of tomatoes allocated to various final products, the beginning and ending of the planting season, can costs and sizes, carton costs, utility costs, and wages for different labor classes used in the different stages of the production process.

Component 2: This part of the model consists of a multi-week simulation loop within which stochastic random values for the key input variables are drawn from specified distributions. Within each iteration of the week a subroutine is called to generate random numbers of daily minimum and maximum temperatures from a multi-variate empirical probability distribution which are used by the model to predict weekly tomato yields conditional on the average daily temperatures occurring over the tomato's fruit set period. The quantities to be processed each week of the planning season, the number of days worked, and the planting dates are also determined in this component. In

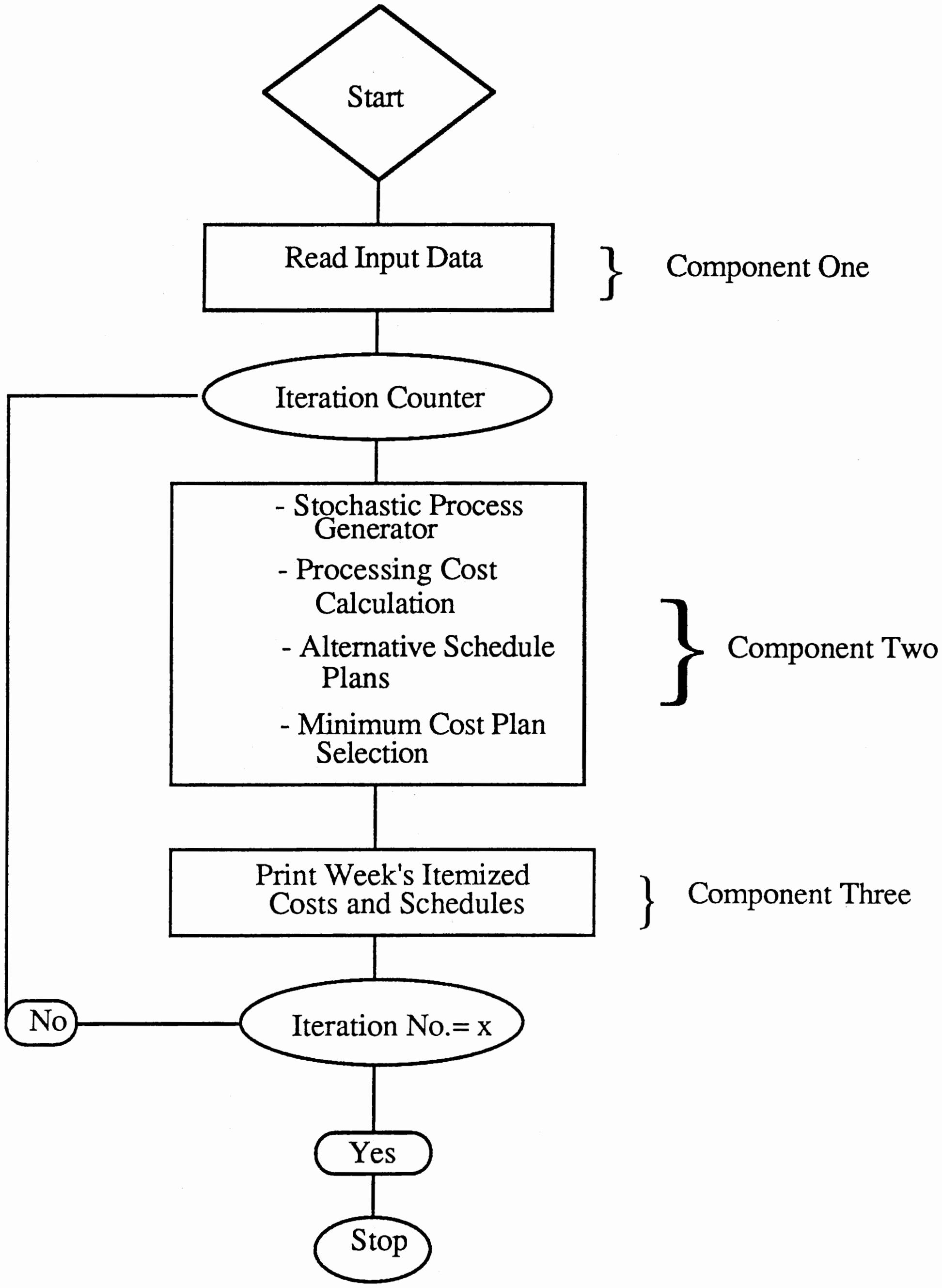

Figure 3. Flow Chart of the Simulation Model

the final step of this component, the model finds the feasible processing combinations, the costs associated with each combination, and selects the minimum cost alternative as the week's planned schedule.

Component 3: The third and final component of the model prints the weekly total yields of raw product, daily whole and processed tomato products, and a table showing the feasible processing combinations along with their costs and the number of shifts required. The selected minimum cost alternative is also printed as well as the number of employees per shift, the raw product equivalent of processed production, and the final production in cases produced each week by each canning line. Summary tables for each week and the whole season's itemized costs are also printed in this component.

Description of the Model

A general description of the model was given above and illustrated by Figure 3. A detailed description of the model structure, required input data, behavioral equations, and definitions of variables will be discussed in this section.

Non–Variable Input Data

Non-variable input data are either read in the first component or defined directly in the model. They include: processing lines for different types of products, capacity of each line in cases of final products, and the case conversion coefficient for each processing line to convert a case of final product into pounds of raw product. Table IV illustrates for each canning line the product produced, can size used, output capacity, cans per case, and the pounds of raw product per case.

Table IV. Product, Can Size, Capacity, Number of Cans Per Case, and Pounds of Raw Product Per Case by Line.

Canning line[a]	Product Produced	Can Size	Capacity	Cans per Case	Raw Product Requirement
			Cases/hr		lbs/Case
1	whole	303	350	24	36.360
2	whole	303	450	24	36.360
3	whole	303	550	24	36.360
4	whole	10	200	6	58.940
5	whole	10	400	6	58.940
6	whole	2-1/2	140	24	64.175
7	whole	2-1/2	450	24	64.175
8	sauce	10	420	6	129.680
8	paste	10	350	6	231.576
9	paste	6 oz.	430	48	102.859
10	paste	12 oz.	500	24	124.431
11	paste	6 oz.	430	48	102.859
12	sauce	2-1/2	300	24	141.200
12	paste	2-1/2	125	24	252.148

[a] Canning lines 8 and 12 can produce sauce or paste.

Source: Logan (1984) and Brand et al. (1978).

The capacity (CAP) per hour shown in Table IV is for a 100 percent operation efficiency for each line. In the model, this capacity is multiplied by .7 to allow for down time caused by equipment breakdown and other stoppages. The actual raw product capacity in tons per hour, Z, is calculated as

$$Z(I) = CAP(I)*0.70*LAMBDA(I)/2000$$

where (I) denotes processing line number 1 through 17, and LAMBDA is the conversion coefficient for pounds of raw product per case. The equation is divided by 2,000 to convert the capacities into tons.

Labor Options

The amount of labor required for tomato processing operations is determined by the operation stages and the number of employees needed to perform a particular job in each stage. There are ten stages in tomato processing and several tasks are performed at each stage.

Based on the full capacity operation of the processing plant defined by Logan and used in this study, the total number of employees required per shift is 235 employees and the minimum number of employees required is 185, even if only one line is used. To determine the appropriate number of workers for a given output, a labor option concept presented by Logan and assumed to fit this application is used. First, the number of workers required to perform each task for a particular canning line represent the full capacity operation for that line, because most of the workers needed for different tasks within different stages remains unchanged regardless of the level of output of the line. Second, the number of workers needed to perform the various services in the 10 stages, when one canning line is operating, is defined as the labor option for that line. Labor option A (LO(A)) is specified for line 1 of the whole tomato processing lines which requires 185 employees to complete the stages of operations on that line. Labor options B, C, D, E, F, and G are specified for lines 2, 3, 4, 5, 6, and 7, respectively. To determine the number of workers required for each option, increments of labor from various classes needed by each option are added to labor option A. For example, the number of employees required for labor option B (LO(B)) is calculated as:

LO(B) = LO(A) + 1 employee - 8 + 1 employee - 10 + 1 employee - 32 = 188 where the numbers attached to right of the word employee reflects the labor class of the processing stage.

Labor option H (LO(H)) is specified for line 8 which adds a certain number of employees to any of the labor options A through G and is used as the base for calculating the labor options for the processed product lines 8 through 12. When processed product lines are working additional shifts without the whole tomato products lines in operation, another labor option (LO(M)) is used as the base to calculate the number of employees for lines 8 through 12. Table XXIII in Appendix A, shows labor class, labor requirements for options A and M, and the equations used to calculate the other labor options.

Labor Wages

Labor is classified according to the type of service performed in each stage of the processing operations and hourly wages are estimated accordingly. The same type of classifications specified by Logan are used with hourly wages updated for the McAlester area in East Central Oklahoma (Center for Economic and Management Research, 1980). Since some labor classifications are not available in the area, approximate classifications in terms of wages and occupations are used. Hourly wages for each class in each stage of the processing operations are illustrated in Appendix A, Table XXIV. The wages are read into the model as non-variable input data along with the number of employees in each class for each stage of the processing operations.

Production Options

Production options show the per day maximum levels of raw products that can be processed by various combinations of processing lines and shifts worked. There are five eight-hour shift possibilities considered in the model: 1, 1.5, 2, 2.5, and 3 shifts each for whole and processed products. Production options considered in the model are of three types as defined by Logan:

a) production options for processing whole tomatoes by different lines for different numbers of shifts worked per day. Assuming that the number of shifts worked are the same across the lines, that is, when 1, 1.5, or 2 shifts is worked on one line, the other lines use the same number of shifts. Therefore, 35 production options of whole tomato processed products are possible (5 possible shifts x 7 line possibilities per shift).

b) production options for processed products when lines 9, 10, and 11 are producing paste and lines 8 and 12 are producing sauce. Production options for these lines are estimated in the same way as above, resulting in 25 possible production options.

c) production options for processed products when lines 8 through 12 are all used to produce paste. Changing lines 8 and 12 from producing sauce to paste would result in the same production options as in (b) above. Since the lines can only produce one product or the other no new production options are created.

The feasible option is selected by determining the average daily output of processed products that can be produced per week. The feasible option for each shift is defined as that production option whose requirements of raw products is greater than or equal to the average daily output requirement of processed products (Logan, 1984). Given the number of days of operations per week and the raw product equivalent of processed, the average daily output of processed products can be determined. With the assumption that the proportion of raw products devoted to processed products are greater than those for whole tomato products, the number of shifts worked on processed products lines are always greater than the number of shifts worked on whole tomato product lines. Therefore, combining production options for whole and processed products there would be 25 possible production options. Furthermore, the possible combinations in which the number of shifts worked for whole are greater than the number of shifts worked for processed products can be disregarded and fifteen production options remain as illustrated in Table V.

Another possible production option is added when the plant is allowed to work for seven days with all lines operating for three shifts for both processed and whole tomatoes. This option is considered only when the expected raw products cannot be processed in six days with three shifts per day. The excess raw product is carried over to the next week if this option is not sufficient. Thus, there are 16 production options considered in the model which in turn determine the production cost alternatives available to the model.

Table V. Production Options for Whole and Processed Tomato Products.

Production option for processed	Production option for whole 1	2	3	4	5
1	1,1	1,2	1,3	1,4	1,5
2		2,2	2,3	2,4	2,5
3			3,3	3,4	3,5
4				4,4	4,5
5					5,5

Tomato Prices

Generally, the tomato processing industry is characterized by a grower-processor contractual agreement promoted by several types of uncertainties in the market. One important factor leading to contractual agreements is uncertain future prices when the processing season begins. Contracts are usually made prior to the start of the planting season to reduce the magnitude of future price risk. In this study, prices are assumed to be established under contractual agreements which will prevail through the processing season with premiums paid for early and late season deliveries. To estimate the costs of growing the crop in the study area, a processing tomato budget was developed and is shown in Appendix B. Twenty percent of the per ton cost was assumed as a reasonable amount to cover the profits to the grower and handling costs. One hundred twenty percent of the per ton cost, $65.54, is used in the model as the accrued cost per ton to the processing plant.

Processed Product Prices

The amount of various forms of processed products to be processed during the season depends on the proportions of the raw products determined for each type which is based on the expected market conditions and the contractual agreements made by the firm. Per case processor prices for processed tomato products published in the Reports on Food Market (American Institute of Food Distribution) and Vegetables Situation and Outlook (United States Department of Agriculture) are used in this model to derive the firm's total revenues and are shown in Table VI for the various forms of final products.

Table VI. Processed Tomato Product Prices.

Product	Can Size	Product Price/Case
		($)
Whole	303	8.00
Whole	303	9.50
Whole	10	10.50
Whole	2 1/2	12.50
Sauce	10	10.25
Sauce	2 1/2	12.50
Paste	10	20.00
Paste	2 1/2	24.00
Paste	6 Oz	12.00

Sources: American Institute of Food Distributions, different issues 1987-88.
United States Department of Agriculture, different issues 1987-88.

Harvesting Dates

Since data are not available to specify the harvesting dates for the tomato crop during the processing season, the growing season was assumed to begin on March 1st and end before December 1st avoiding severe weather conditions during the remaining months. The processing season is contained in this period and the earliest possible harvest date was decided upon by running the model several times for alternative harvest dates. The harvest date that produced the earliest possible planting date after March 1st was selected and was found to be the 120th day of the planting season which corresponds to June 28th.

Another set of non-variable input data consists of the acres to be planted and the proportions of raw products allocated to whole tomato processing, paste, and sauce.

Variable Input Data

Utility Requirements

A major part of the costs incurred in the processing operation is the utility costs. Electricity, natural gas, and water requirements by the processing firm are derived on the basis of the physical units used per ton of raw product processed into whole or processed products. These requirements are estimated by Logan as shown in Table VII. Costs of utilities based on Oklahoma rates are estimated at $.068 per kwh for electricity, $.67 per therm for natural gas, and $.00165 per gallon for water.

Table VII. Utility Requirements Per Ton of Raw Product by Type of Processed Products.

Final Product	Electricity	Natural gas	Water
	Kwh/ton	therms/ton	gal/ton
Whole Tomatoes	42.532	17.553	946.284
Sauce	10.008	25.101	946.284
Paste	10.008	18.431	946.284

Source: Logan, 1984, p. 10;
Stillwater Electric Utility, Stillwater, Oklahoma; and
Oklahoma Natural Gas Company.

Evaporator Clean-up and Boiler Start-up Costs

Whenever any of the processed products processing lines is closed or less than three shifts are worked per day, evaporator clean-up costs are incurred. If three shifts are worked per day, costs are incurred only once a week or less. The processing lines have to be cleaned and set ready for the next time's use whenever they stop processing. Five evaporators are used in the program as Logan has specified, one for each of the five processing lines.

Boilers are used in the cannery plant for hot water needed for tomato processing operations by processed products processing lines 8, 9, 10, 11, and 12. Two boilers with the capacity of 80,000 and 120,000 pounds are used in this model. When less than three shifts per day are worked, the boilers must be reheated for the next operation. The estimated per service evaporator clean-up and boiler costs for different combinations of the processing lines, where the requirements for lines 8, 9, and 10 are assumed to be met by the larger boiler and lines 11 and 12 are met by the smaller, are given in Table VIII. Logan obtained the chemical compound costs per evaporator clean-up and boiler start-up service from industry sources. In this application, the boiler start-up costs are assumed to be estimated on the basis of the natural gas costs, thus Logan's estimates are divided by the per therm cost of natural gas to obtain the amount of therms then multiplied by the per therm cost rate for Oklahoma. The per unit costs are defined directly in the model from which the weekly costs are derived.

Table VIII. Clean-up and Boiler Start-up Costs Per Occurrence.

Line	Boiler Start-up	Evaporator Clean-up	Total
	$	$	$
8	2,000	300	2,300
8,9	2,000	600	2,600
8,9,10	2,000	900	2,900
8,9,10,11	3,340	1,200	4,540
8,9,10,11,12	3,340	1,500	4,840

Source: Logan, 1984, p. 11.

Another set of input data included in this category consists of the number of cans per case of final product based on can size, can costs, costs of cartons needed to pack the final products, and costs of lye and salt required for whole tomato processing. The per unit costs of these items are shown in Table IX and are written directly in the model from which the weekly incurred costs are derived. Salt requirements are calculated on the basis of the amount of tablets needed per case of final product.

Stochastic Variables

Variation in weather temperatures and yields have the most effect on the tomato processing decision maker. Accounting for a wide range of possible outcomes provides the tomato processor with a chance of incurring costs during the processing operation upon which he would be willing to take action.

The model uses stochastically estimated daily maximum and minimum temperatures generated from a multivariate empirical probability distribution. These temperatures are then used to estimate the duration of the fruit set period and the planting date of the tomato plant employing the heat unit concept.

The model also uses this concept to generate stochastic tomato yields conditional on the average daily temperatures occurring over the fruit set period.

Temperatures

Weather variabilities have a significant influence on the fruit set stage of development which is considered as the crucial period in determining yield. Daily maximum and minimum temperatures for thirty-three years of historical data for the McCurtain area are obtained from Oklahoma Climatological Data

Table IX. Number of Cans, Can and Case Cost, Carton Cost, and Number and Cost of Salt Tablets.

Can Size	Cans/case	Cost/can	Cost/case	Cost/carton	Salt	Cost/ tablet
	No.	$	$	$	Tablets	$
303	24	0.100	2.40	0.178	24	0.0030
303 (stewed)	24	0.100	2.40	0.178	24	0.0022
2-1/2	24	0.175	4.20	0.265	24	0.0053
10	6	0.500	3.00	0.225	12	0.0099
6 oz.	48	0.085	4.08	0.143		
12 oz.	24	0.120	2.88	0.138		

Source: American Can Association, 1988 and Logan, 1984, p. 11.

(U.S. Dept. of Commerce) for the years 1954 through 1986 beginning the first day of March until the end ofNovember. January, February, and December months are excluded to avoid severe cold weather which may not permit planting or growing tomatoes. Given that some data prior to 1954 are not reported, the thirty-three years of data are assumed to provide enough data for daily maximum and minimum temperatures distributions. To generate stochastic temperatures, multivariate empirical distributions functions are estimated using the thirty-three years of historical data.

Clements et al., (1971) developed a procedure for correlating normally distributed events in simulation models. The procedure was later modified by Richardson and Condra (1978) into a general procedure which can be used to generate correlated random variables from different distributions. Following their work, the first step in using the procedure to generate stochastic random temperatures from the empirical distribution is to calculate the correlation coefficient matrix from the historical data. Using the square-root method, the matrix is factored into an upper triangular matrix. The next step in developing the distributions is to compute the deviations from the mean value for the daily maximum and minimum temperatures for each of the thirty-three daily temperatures, and then ranking the deviations in an increasing order (Richardson and Condra, 1978; and Law and Kelton, 1982). A FORTRAN computer program is used to estimate the unique upper triangular matrix and the ordered deviations and the output was stored for later use. The third step is to generate a vector of independent standard normal deviates. A random normal deviation generator [RANF(IX)] obtained from the computer center at Oklahoma State University is used to generate the deviator. The following step is to generate a vector of correlated pseudo-random numbers distributed standard normal using

$$C = RW$$

where R is the factored correlation matrix indicated earlier and W is the vector of independent random normal deviates. The C vector is then transformed into a vector of pseudo-random numbers distributed uniformly on the scale of zero to one. The transformation equation can be written as

$$U = 0.5 + \left[0.5\ \mathrm{ERF}\left(\frac{C}{\sqrt{2}}\right)\right]$$

where U is a vector of pseudo-random numbers distributed uniformly (0,1), ERF is an IBM supplied function for integrating the area under the standard normal probability function of its random deviates C. The values obtained for the U vector are used to project the values on the cumulative distributions function for the random variables by the use of the inverse cumulative distribution function transformation method (Law and Kelton, 1982; Meier et al., 1969; and Guiterrez, 1985). For the variable of interest, say Y, the method involves taking the cumulative distribution function, say F(Y) and, setting it equal to the uniformly distributed random value U. The equation is then solved for Y to obtain the inverse function $Y = F^{-1}(U)$. Each time a value for U is substituted into $F^{-1}(U)$ for a corresponding value for Y is obtained. Graphically, this method is illustrated in Figure 4 for the one variable case, where, y_1 and y_2 are projected by their respective uniform random values U_1 and U_2.

Richardson and Condra presented a mathematical formula to generate random values from the empirical distribution for the three internal cases:

$$Y_i = a + (b-a)(U_i) \quad , 0 \le U_i \le P_1$$

$$Y_i = b + (c-b)\left(\frac{U_i-P_1}{P_2-P_1}\right), P_1 \le U_i \le P_2$$

$$Y_i = c + (d-c)\left(\frac{U_i-P_2}{1-P_2}\right), P_2 \le U_i \le 1$$

$$\text{for } a < b < c < d \qquad , a < Y_i < d$$

where, U_i is a uniformly distributed random number over the interval zero to one, a, b, c, and d represent the values of Y_i at which the slope of the cumulative distribution function for Y changes, and P_1 and P_2 represent the probabilities.

A modified version of Richardson and Condra's FORTRAN computer program for drawing random numbers from a cumulative distribution function was used in the model as a subroutine to generate stochastic temperatures. Each time the iteration loop is used the subroutine is called and a random maximum and a random minimum temperature is generated.

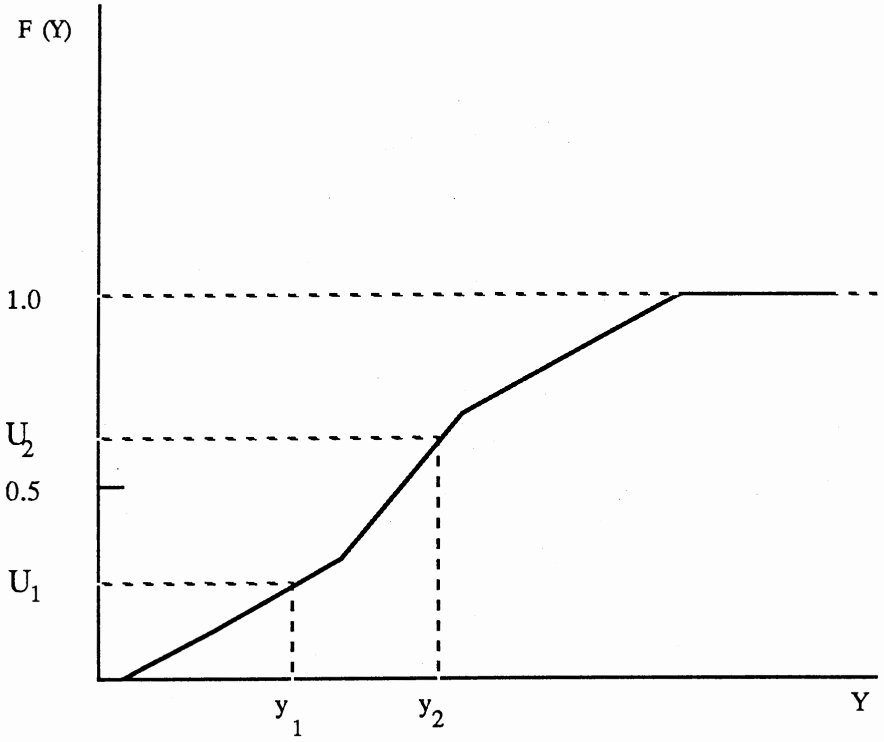

Figure 4. Graphical illustration for drawing random values from the cumulative distribution

Tomato Yields

Data for tomato processing yields are not available from Oklahoma and using historical data from other states or the U.S. average yields implicitly assumes that the climatic conditions in Oklahoma are similar to those states and the realized yield distributions of the past years are the same as the anticipated distributions. The probability distributions of economic variables change over time in the real world, and the decision-maker is faced by the uncertain outcomes for which he must form expectations (McSweeny et al., 1987). Supporting this view an estimation procedure to predict tomato yields conditional on the average daily temperatures occurring over the crucial stage of development of the tomato plant was developed in this study.

The Estimation Approach.

The purposes of this procedure are to predict the time period over the crucial stage of tomato plant development and to estimate tomato yields conditional on the average daily temperature occurring over that stage which will be used to estimate the yields.

The first step of the procedure is to specify the crucial stage in tomato plant development at which unfavorable temperatures will have the most influential impact on yields. Tomatoes pass through several stages of growth during the season. Seedling stage, vegetative stage, flowering stage, fruit setting, and maturity stages all require a certain amount of heat units to develop. The rate of plant growth is determined primarily by the level of temperature to which the tomato plant is exposed. Figure 5 illustrates the approximate effect of temperature on the vegetative growth of the tomato plant. Plant growth increases rapidly as temperature increases above a certain minimum threshold, then it increases at a decreasing rate up to an upper limit beyond which growth

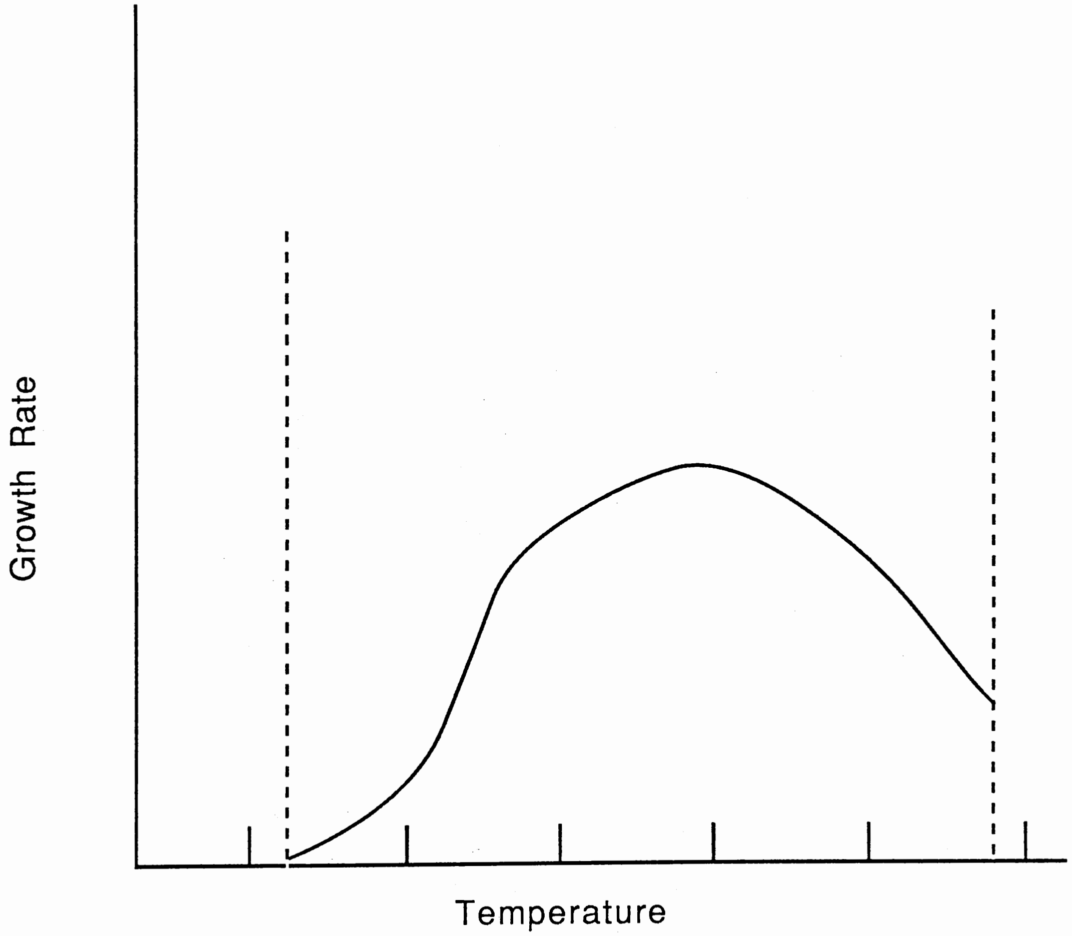

Figure 5. Approximate effect of temperature on the growth rate of tomato plant

declines (University of California, 1983; and Logan and Boyland, 1983; and Owens and Moore, 1974). Excessively high or low temperatures may have a negative effect on the plant growth stages causing delay of development or may even cause plant retardation. Day temperatures above 94°F or night temperatures below 60°F will not permit flowers to set fruits for economical yields (McCraw et al., 1987). The fruit setting stage is recognized by Motes as a very critical stage of the plant development when changes in temperatures will have the most important impact on yields. In this study, the fruit set stage is considered the crucial stage which provides essential information to estimate the yields.

The second step in the estimation procedure is to determine the number of days elapsed during the fruit set stage. Bush processing tomato varieties are usually used for mechanical harvesting and can be harvested in a single pick due to the fact that bush processing tomato varieties produce flowers and set fruits in a relatively short period (University of California, 1985). Fruit set is expected to be relatively uniform which suggests a consistent fruit set interval among plants planted at the same time.

To determine the length of the duration period of a particular growth stage, an estimated amount of the effective heat units used by the tomato plant to complete that stage is required. The concept of heat units or degree days is a mechanism used to measure the heat units required by the plants to develop. It refers to the amount of heat units that accumulate during a 24-hour period when the average daily temperature is one degree above the developmental threshold (University of California, 1985).

Several methods are available to calculate heat units. Some of them include: a) the approximate mean method; b) the corrected mean method; and c) the Sine function method. The first method calculates the degree days (DD) or heat units accumulated in one day by taking the average of the maximum (T) and minimum (t) temperature for that day and subtracting a base (B) temperature from it where the base temperature is the minimum temperature above which the plant starts to grow. The formula can be written as

$$DD = \left(\frac{T - t}{2}\right) - \text{Base}$$

This method does not correct for the upper temperature limit. The second method was developed to overcome this problem and for exclusive high temperatures. The amount of heat units (HU) accumulated during a particular day is estimated according to the following formula:

$$HU = \left[\frac{T + t}{2} - (T - X)\right] - B$$

where, T is the maximum temperature during that day, t is the minimum temperature, X is the upper limit temperature, and B is the minimum base temperature.

The Sine Function method determines the heat units accumulated during a 24-hour period by integrating the Sine Function between the minimum temperature in day one to the minimum temperature in day two in a 24-hour period. This method was developed by Logan and Boyland to increase the precision of calculating the heat units by approximating the behavior of temperatures occurring during the day. Logan and Boyland employed the Sine function and the approximate mean methods to calculate the mean amount of heat units required by the processing tomato plant from first day of planting to the first day of harvest using planting and harvesting dates from four major commercial locations in California. They argued that the results obtained by the Sine function, presented in Table X, were less dispersed compared to the approximate mean method and performs more consistently on the average.

Table X. Estimated Heat Unit Requirement for Tomatoes at Four Major Locations in California for Two Different Estimation Methods.

	Sine Function			Approximate Mean		
Location	Heat Unit Mean	Standard Deviation	Coefficient of Variation	Heat Unit Mean	Standard Deviation	Coefficent of Variation
	(C°-days)			(C°-days)		
Davis (n=32)	1,742	144	0.0826	1,914	184	0.0961
Clarksburg (n=15)	1,819	132	0.0725	1,960	147	0.0750
Winters (n=14)	1,871	117	0.0625	2,114	154	0.0728
Woodland (n=24)	1,836	158	0.0862	2,094	200	0.0955

Source: Logan and Boyland,1983.

Owens and Moore (1974) employed four methods, the approximate mean, the exact mean, the corrected mean, and the median minus base, to estimate heat units requirements by the tomato plant cultivar "Chico" from the time of seeding to the time of 75 percent maturity at Scott, Mississippi. The results showed a significant difference in the mean amount of heat units required by the cultivar among the methods tested. The mean heat units varied from 1,462 with a base temperature of 55°F and a ceiling temperature of 80°F using the corrected mean procedure to 3,932 heat units with a base of 40°F and no ceiling temperatures using the approximate mean method. Their findings indicate that the amount of heat units obtained depends on the minimum temperature used as a base, the maximum temperature used as a ceiling, and the method used. They suggested that the most precise method was the corrected mean when using a ceiling temperature of 80°F and a base of 40°F. The mean amount of heat units required by the cultivar using this method at first flower, 65 percent fruit maturity, and 75 percent fruit maturity of growth stages were 1,142; 3,028; and 3,236 heat units, respectively. Table XI illustrates heat units requirements by the Chico cultivar from seeding to various stages of growth obtained by the corrected mean method.

Even though the Sine function method is considered a better procedure, the corrected mean method was used to estimate the number of days needed to obtain the required heat units due to the results reported by Owens and Moore for several growth stages and the similar plant growing conditions between their study area and those of Southeastern Oklahoma.

Table XI. Heat Unit Requirements by the Chico Processing Tomato Cultivar at Scott, Mississippi, from Seeding to Various Stages of Growth with 80°F Ceiling and 40°F Base Temperature.

Stage of Growth	Planting Dates				Mean of 4 Dates	Coefficient of Variation	Day Range
	3/31	4/20	5/10	5/19			
Cotyledon expansion	360	434	372	357	380	9.59	2.6
First Leaf	503	555	482	448	497	9.02	3.6
Third Leaf	622	684	666	598	642	6.14	2.9
First Flower	1,329	1,158	1,013	1,066	1,142	12.14	10.1
65% Maturity	3,038	2,990	3,018	3,068	3,028	1.08	2.6
75% Maturity	3,327	3,167	3,272	3,276	3,236	1.57	3.6

Source: Owens and Moore, 1974, p. 6.

The mean amount of heat units required by the plant during the first flower through 65 percent of fruit maturity was estimated by Owens and Moore using the corrected mean method for the Chico cultivar as 1,886. Under the conditions of limited data available for the study, the amount of heat units used by the plant from the establishment of first flower to 10 percent maturity was assumed as an approximate measure for the duration of the fruit set stage. The final step of the procedure is to obtain subjective assessments of yields conditional on the average daily temperatures over the fruit set stage estimated in the previous step.

In the absence of data, triangular probability distributions for economic events are used by many researchers in simulation models because they are easy to estimate and do not require the tedious probability estimations involved to elicit other distributions. The triangular probability distribution can be completely identified by the minimum, maximum, and most likely value of the variable of interest as shown in Figure 6.

Triangular probability distributions are used to generate stochastic tomato yields conditioned on the average daily temperatures occurring over the fruit set stage period specified by the stochastic heat unit required by the plant during this stage. The minimum, maximum, and modal values for tomato yields obtained from the Horticultural Department at Oklahoma State University are illustrated in Table XII (Motes, 1988).

Under average daily temperature of 70°F to 80°F, the most likely yield was assessed at 20 tons/acre. A forty to sixty percent reduction in yield, as a result of reduced fruit set, is expected if the average daily temperature drops to 65-69.9 range due to low night temperatures during the fruit set period. Also, an

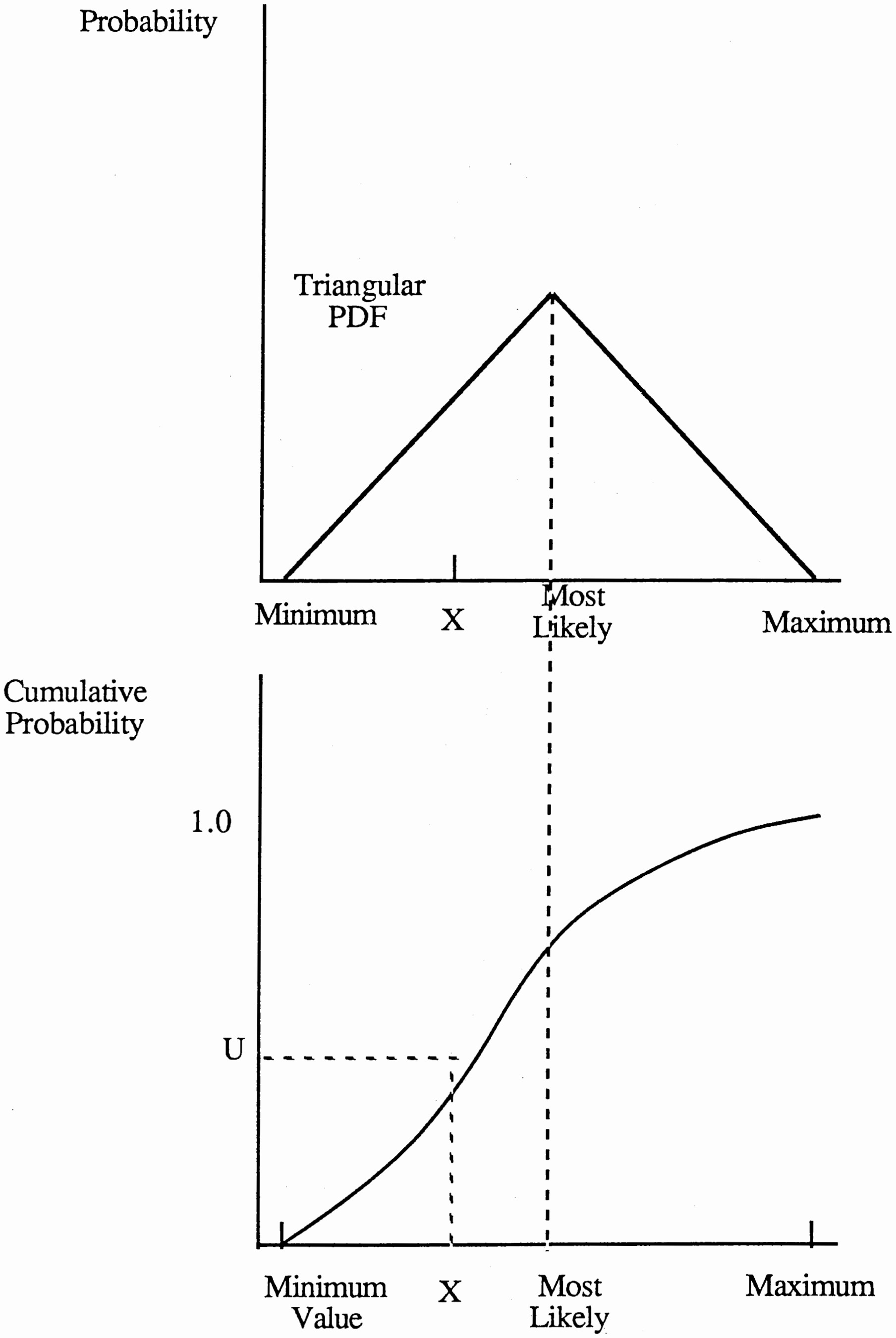

Figure 6. Graphical Illustration of Generating Random Variable X which has a Triangular Probability Distribution.

increase in the average daily temperature up to 80°F-85°F produces almost the same reduction in yield but due to high daytime temperature during the fruit set period. When the average daily temperature drops below 65°F or rises above 90°F the tomato plant is not expected to set fruits due to very low night temperatures in the spring or very high temperature in the summer.

Table XII. Processing Tomato Yield Assessments.

Average temperature range during the fruit set stage	Most Likely (Modal)	Maximum Yield	Minimum Yield
	tons/acre	tons/acre	tons/acre
60-64.9	0	0	0
65-69.9	10	12	8
70-74.9	20	24	15
75-79.9	20	25	15
80-84.9	16	18	12
85-89.9	10	12.5	7.5
90-Over	0	0	0

Source: Motes, 1988.

To generate the stochastic random yields a FORTRAN subroutine RANF(IX) is called within each iteration of the simulation loop to draw random normal deviates. The deviates are then transformed into a uniform zero to one distribution by the following equation

$$U = 0.5 + \left[0.5 * \mathrm{ERF}\left(\frac{D}{\sqrt{2}}\right)\right]$$

where , U is a uniform random value distributed (0, 1), and ERF is the error function to integrate the area under the standard normal density function for the deviate D.

Next, the obtained U values are used in the inverse transformation function to project the corresponding yield values as shown in Figure 6. The triangular cumulative distribution function as presented by Sprow (1967) can be written as

$$F(x) = (x - a)^2/\left[(b-a)(m-a)\right], \qquad a \le x \le m$$
$$= 1-(b-x)^2/\left[(b-a)(b-m)\right], \qquad m \le x \le b$$

where, X is the random variable, a is the minimum, m is the most likely value, and b is the maximum value.

Equating F(x) to the uniform variate U and solving the above equations for x, the value left of the mode, x_L and the value right of the mode, x_R can be derived,

$$X_L = a+\left[U(b-a)(m-a)\right]^{.5}, \qquad 0 \le U \le (m-a)/(b-a)$$
$$X_R = b-\left[(1-U)(b-a)(b-m)\right]^{.5}, \qquad (m-a)/(b-a) \le U \le 1$$

Annualized Costs

To determine the expected profits for the processing firm, equipment and construction costs are obtained through written and phone call requests to several manufacturing and professional sources, and Snyder et al., (1988). The costs of processing lines (based on can size and raw product capacity) and all necessary equipments for handling empty cans, filling operations, and full can warehouse departments are provided by Richard Gomez of Custom Food Machinery Inc., California. These costs are shown in Table XIII. Processing building costs are estimated on the basis of the area needed per each

Table XIII. Costs of Processing Lines for the Proposed Processing Facility.

Line	Product	Can Size	Capacity, Raw Product	Cost	Annualized Cost
			Tons/hr	$	$
1	Whole	#303	6.365	520,000	68,380
2	Whole	#303	8.18	520,000	68,380
3	Whole	#303	10.00	520,000	68,380
4	Whole	#10	5.9	560,000	73,640
5	Whole	#10	11.80	560,000	73,640
6	Whole	#2 1/2	4.50	520,000	68,380
7	Whole	#2 1/2	14.43	520,000	68,380
8	Sauce	#10	27.23	650,000	85,475
9	Paste	6 oz.	21.11	425,000	55,888
10	Paste	6 oz.	21.11	425,000	55,888
11	Paste	12 oz.	31.10	425,000	55,888
12	Sauce	#2 1/2	21.18	520,000	68,380

Source: Gomez, 1988.

processing line and the construction cost per square foot. Each processing line requires about 65,000 square feet of building. Investment requirements for the processing facility and associated costs, as well as the annualized costs are shown in Table XIV. Equipment is amortized for 15 years, buildings for 20 years, and land for 40 years at 10 percent. Start-up costs include costs incurred during the construction period prior to start of the processing operations such as management costs, travel, employee recruitments, and professional services. Annual management salaries include salaries for the general manager, production manager, procurement manager, sales manager, fieldman, and 20 percent fringe benefits. Processing center building cost is estimated at $50 per square foot, while warehouse building cost is estimated at $20 per square foot.

Table XIV. Investment Requirements and Associated Costs.

Item	Cost	Annualized Cost
	$	$
Processing Lines	6,165,000	810,698
Buildings		
Offices	650,000	85,475
Processing Center	39,000,000	4,582,500
Paving	550,000	64,625
Warehouse	1,444,500	169,729
Additional Facilities		
Boiler Room	250,000	32,850
Shop & Lab equipments	290,000	38,106
Land (30 acres)	30,000	3,069
Waste Disposal System	750,000	98,550
Other		
Management Salaries		234,000
Start-up Capital	445,000	58,473
Equipment Installation	850,000	111,690
Contingency (10%)	5,042,400	662,570
TOTAL	55,466,900	6,887,710

CHAPTER IV

MODEL VALIDATION AND RESULTS

The previous chapter was concerned with the formulation and construction of the model, the development of the required input data, and stating some of the assumptions regarding the stipulated logical structure of the model. This chapter discusses the steps involved in validating and verifying the model, presents the results obtained from the simulation runs of the model, and analyzes the output responses obtained.

Model Validation

To test the degree of the model credibility in simulating the actual system, the model is investigated through verification and validation processes. Verification is conducted during the construction stages of the model and after the model has been developed. It is concerned with the investigation of the logical structure of the model to verify if the model serves the purposes it is intended to perform. The validation pertains to the comparisons of the key statistics from the actual system represented by the model. For the models which are suggested to represent a system for which no actual data are available, validation can be performed by rigorous examination of the model structure (Meier et al., and Mihram, 1972).

An important aspect of model verification when stochastic processes are considered in the simulation model is the distributions of the variables intended to have a random behavior. The selection of the seeds for random number generation on which the randomness process is based should be random and independent from one another. In this study, the model uses a random number generator called GAUSE, written in FORTRAN and incorporated in the model as a subroutine, to generate random numbers used as the seeds for drawing random tomato yields from triangular probabilities and random temperatures from empirical probability distributions.

Another step taken to verify the model is the investigation of its logical structure. The model is run deterministically for several times and checked for syntax errors. The stochastic processes are then introduced directly or as a subroutine into the model, which facilitated easier construction and less complicated syntax.

Stochastic Temperatures

The stochastic maximum and minimum temperatures expected during a particular day of the planning season are drawn from multivariate cumulative empirical distributions using thirty-three observations for each day from thirty-three years of historical data for the McAlester area in southeastern Oklahoma.

To account for the statistical dependence between daily high and low temperatures, a correlation coefficient matrix for each series of daily low and high temperatures was computed. The square-root method presented by Clements et al., (1971) is applied to factor these matrice into unique upper triangular matrices. The obtained coefficients are read into a modified version of Richardson and Condra (1978) FORTRAN computer program to draw correlated random variables from empirical probability distributions as non-variable input data. Each time the program is executed the subroutine GAUSE is called to generate independent random standard normal deviates used to draw the random numbers from the distributions and the number of iterations is increased parametrically until statistically satisfactory results are obtained. The estimated correlation coefficients for the actual and simulated daily low and high temperatures obtained for selected days from 80 iterations are listed in Table XV. The actual and simulated maximum, minimum, mean, and standard deviations for the day's high and the day's low temperature for the same iterations are listed in Table XVI along with the t-statistics and the chi-squared values. The t-statistic is used to test the hypothesis that the simulated mean is equal to the actual mean and the chi-square test is used to test the hypothesis that the standard deviation of the simulated temperatures is equal to the standard deviation of the actual temperatures. Both the t-test and chi-square test are applied at $\alpha = .05$ significance level. The statistics shown in Tables XV and XVI are selected arbitrarily as the first day of each month to limit the length of the data reported. Of the 550 means tested only 12 means failed the t-test and all of the 550 standard deviations tested passed the chi-square test.

Figures 7, 8, and 9 graphically compare the observed with the population cumulative distributions of daily high and low temperatures for three days of the season.

Stochastic Tomato Yields

The elicited maximum, modal, and minimum values for tomato yields conditional on the average daily temperature during the fruit set period were used in the model to develop triangular probability distributions from which stochastic random tomato yields are generated as discussed in the previous chapter. The model uses the heat unit concept to predict the time and the

Table XV. Correlation Coefficients Between Daily Low and High Temperatures for Selected Days of the Season.

Date	Correlation Coefficients	
	Actual	Simulated
March 1	0.753	0.692
April 1	0.624	0.692
May 1	0.390	0.458
June 1	0.550	0.544
July 1	0.548	0.574
August 1	0.675	0.663
September 1	0.531	0.464
October 1	0.524	0.593
November 1	0.753	0.739

Table XVI. Selected Statistics for the Actual and Simulated Day High and Low Temperatures.

	Maximum		Minimum		Mean		T-Statistic	Standard Deviation		Chi square
Date	Actual	Simulated	Actual	Simulated	Actual	Simulated	α = .05	Actual	Simulated	Value,α=.05
Day's High Temperatures °F										
March 1	78.00	78.00	25.00	27.54	59.39	58.45	-0.655	12.96	11.64	70.941
April 1	88.00	87.92	52.00	52.00	71.79	70.95	-0.862	8.73	9.36	84.650
May 1	88.00	88.00	61.00	61.28	75.61	75.41	-0.258	6.95	6.99	79.466
June 1	96.00	94.36	73.00	73.00	82.51	82.43	-0.147	5.32	5.07	75.330
July 1	103.00	102.98	74.00	78.39	91.12	92.09	1.384	6.25	5.79	73.174
August 1	106.00	105.19	79.00	80.32	94.15	94.59	0.620	6.37	5.82	72.129
September 1	102.00	101.52	66.00	67.03	90.24	90.11	-0.149	7.83	6.88	69.461
October 1	96.00	95.77	63.00	63.00	80.70	81.64	0.963	8.79	7.62	68.472
November 1	82.00	81.81	51.00	51.48	69.42	70.43	1.013	9.18	8.51	73.220
Day's Low Temperatures °F										
March 1	63.00	58.73	15.00	16.44	36.54	34.59	-1.417	12.34	9.99	63.941
April 1	67.00	66.86	25.00	25.02	47.18	47.88	0.572	10.98	11.96	86.109
May 1	69.00	68.96	40.00	40.64	54.88	53.87	-1.050	8.57	8.32	76.681
June 1	74.00	73.84	45.00	45.92	61.61	61.94	0.410	7.24	6.41	69.902
July 1	79.00	78.80	32.00	62.33	71.49	71.80	0.724	3.83	3.80	78.277
August 1	77.00	76.40	61.00	61.01	70.46	71.05	1.356	3.93	3.46	69.595
September 1	78.00	78.00	55.00	55.16	69.30	69.56	0.404	5.70	5.68	78.697
October 1	69.00	69.01	37.00	36.18	55.46	57.36	1.850	9.22	9.56	81.936
November 1	68.00	67.33	20.00	22.80	46.64	48.09	1.125	11.55	10.30	70.400

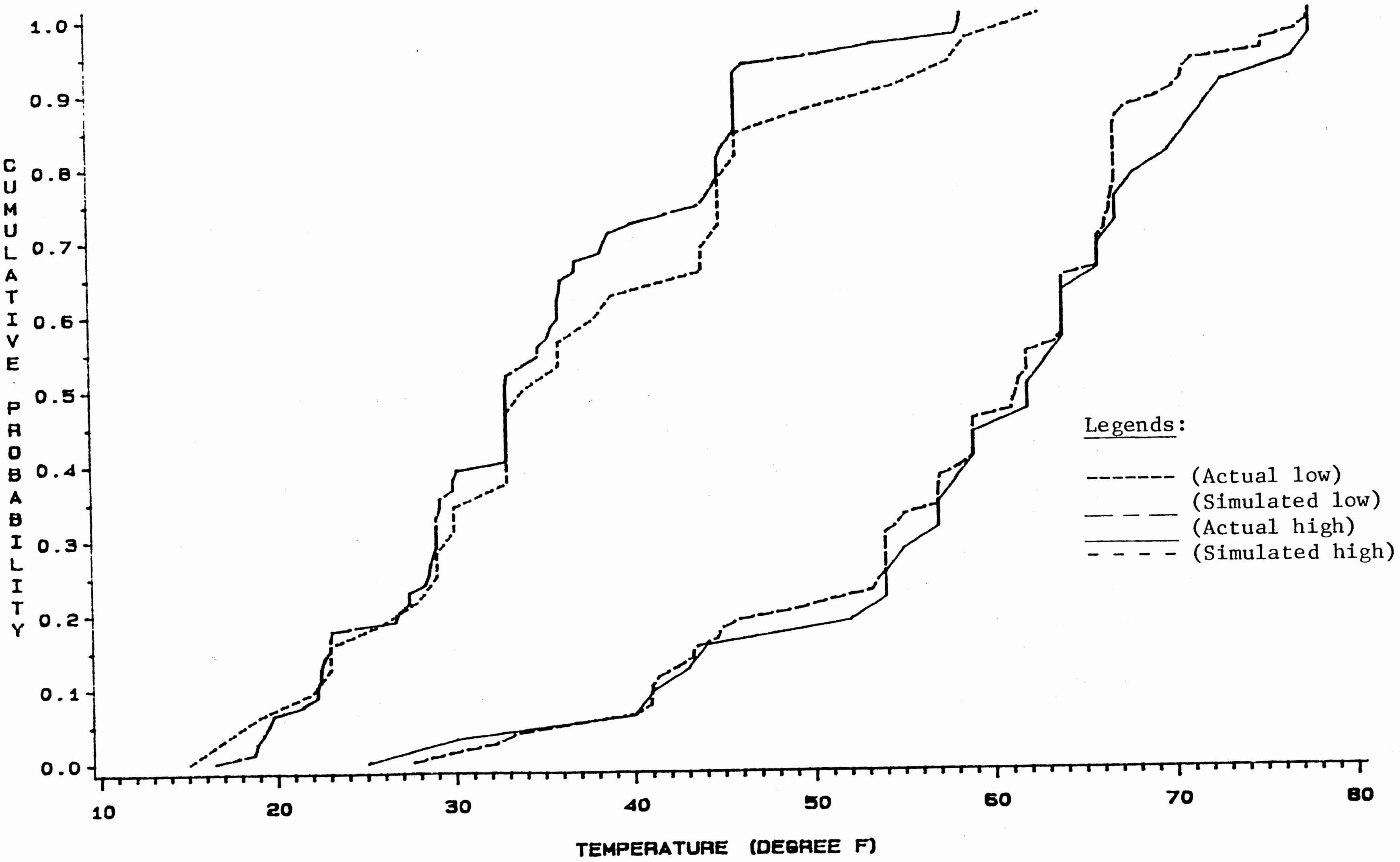

Figure 7. Actual and Simulated Cumulative Probability Distributions for the Daily Low and High Temperature of March 1.

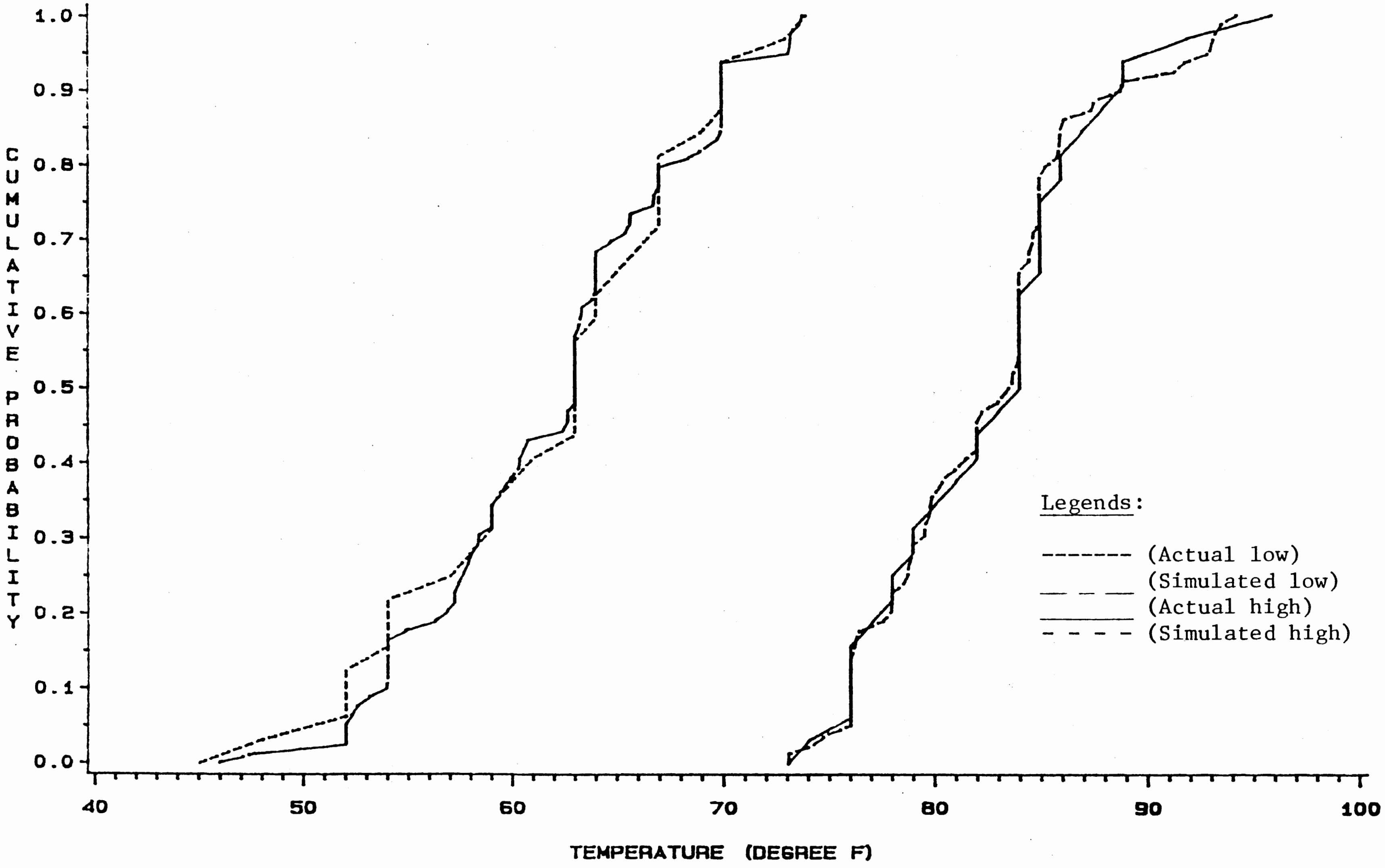

Figure 8. Actual and Simulated Cumulative Probability Distributions for the Daily Low and High Temperature of June 1.

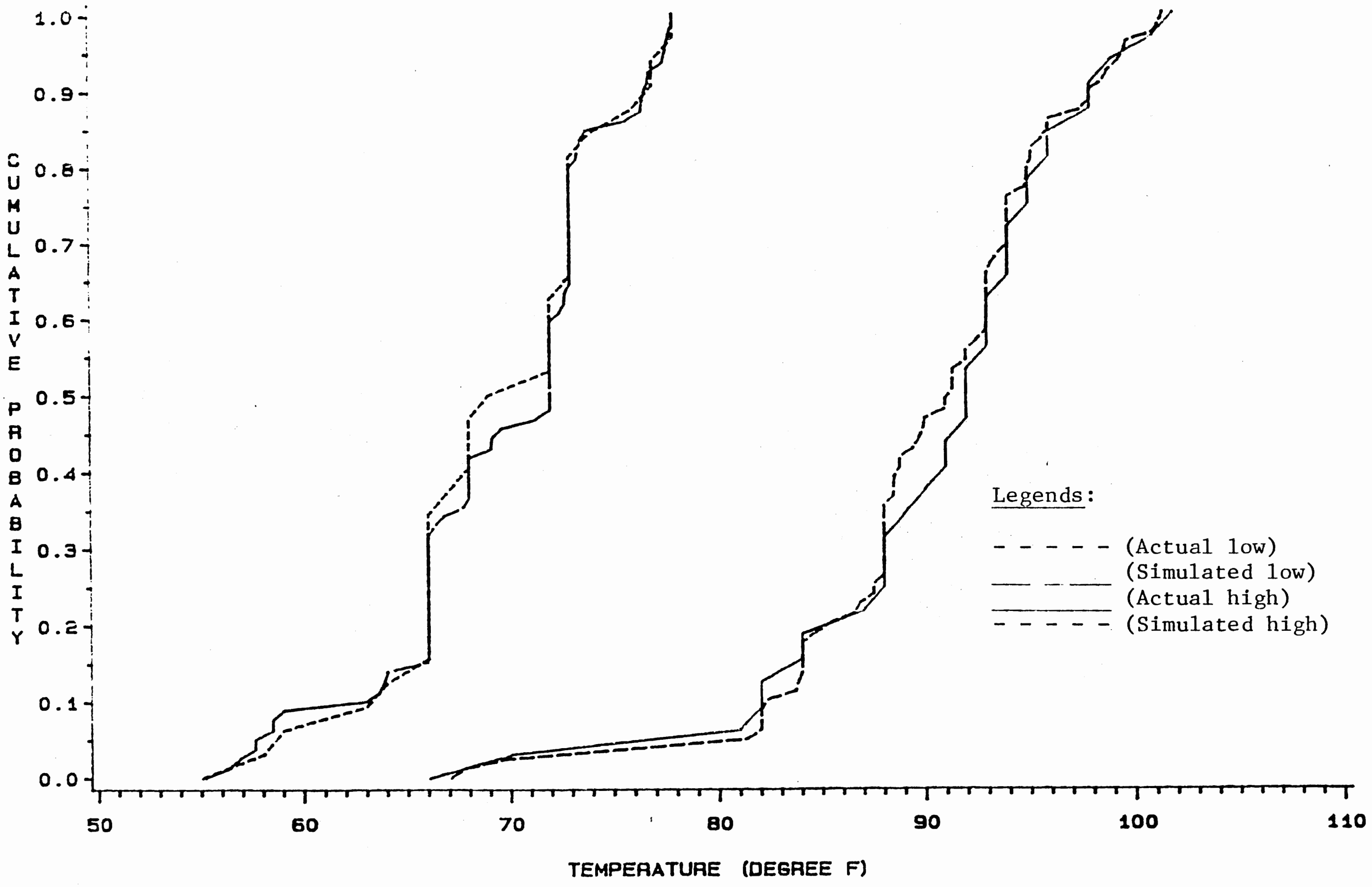

Figure 9. Actual and Simulated Cumulative Probability Distributions for the Daily Low and High Temperature of September 1.

length of the fruit set period based on a given amount of heat units required by the tomato plant to complete the particular stage. The average daily temperature occurring over this period was then used as a condition to draw the random yields from the triangular distributions for each week of the planning season.

The observed conditional probability distributions obtained from 80 iterations are presented graphically in Figure 10 for five ranges of the average temperatures occurring over the fruit-set period.

Simulation Results

The main objectives of this study are to determine the least cost combination of weekly processing schedules for a tomato processing firm in the study area and to analyze the impact of stochastic weather and yields on costs of processing. A deterministic simulation model available from California is greatly modified into a stochastic simulation model to generate stochastic temperatures, yields, and planting dates for the crop. The heat unit method is used to predict the time and length of the processing tomato plant fruit set stage of growth over which the daily average temperatures could be estimated and used to generate random stochastic yields from triangular probability distributions.

This section of this chapter presents and evaluates the results obtained from running the model for 80 iterations. The model is constructed on the basis of several decisions that are made prior to the start of the processing season. These decisions include: 1) the number of acres to be planted for the tomato crop, 2) the starting time of the processing season, 3) the allocation of the raw product to the various forms of final products, 4) the priority with which the final

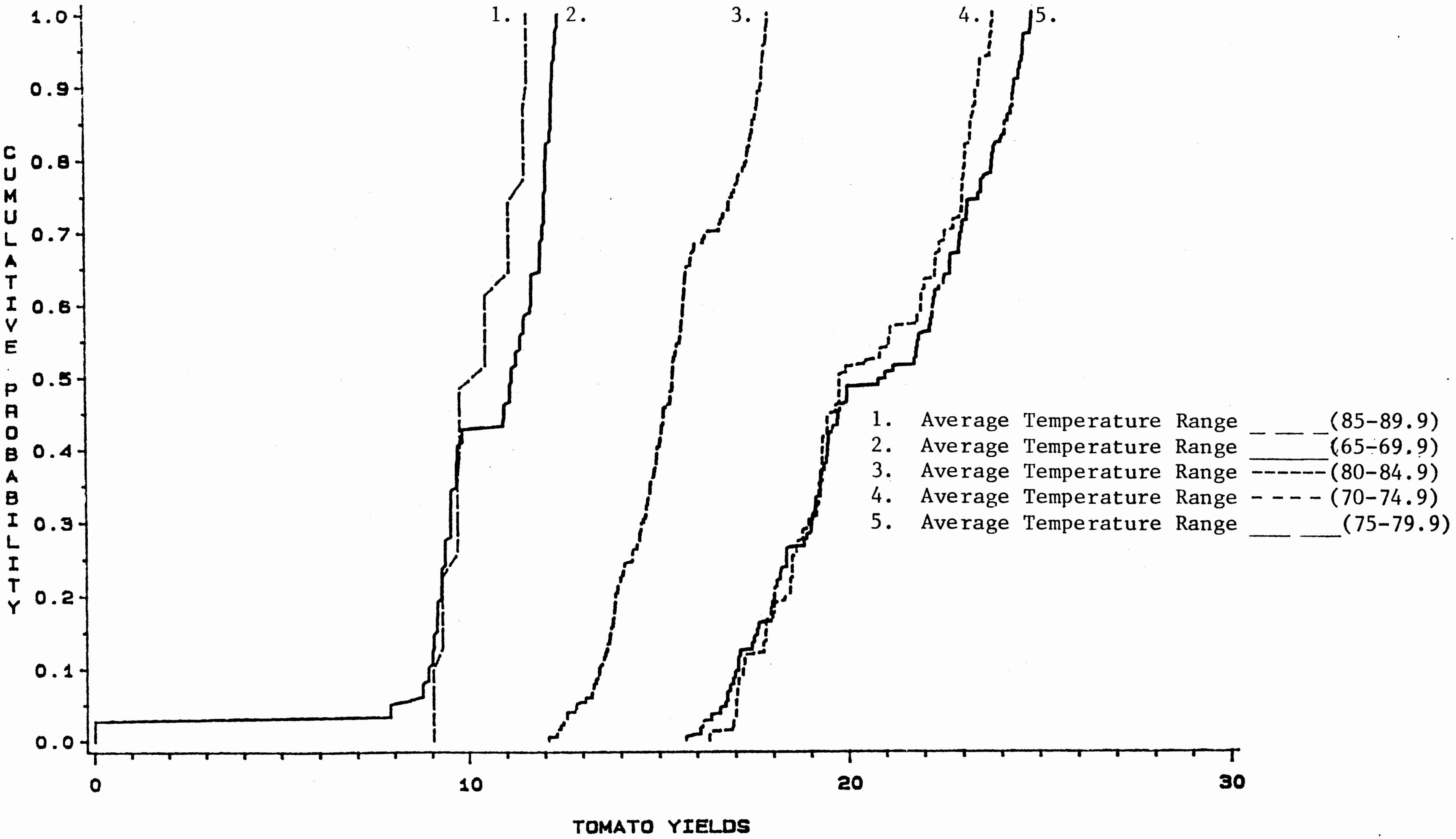

Figure 10. Cumulative Probability Distributions for Tomato Yields Given the Range of Average Daily Temperatures over the Fruit Set Period.

products are to be produced, and 5) the number of shifts per day and the number of days per week that can be worked.

To estimate the number of acres needed to supply the firm with the raw products, the per acre yield has to be known. Since tomato yields are generated stochastically in this model, the number of acres is set at 400 as an initial specification. As discussed earlier in Chapter III, the earliest day to begin the processing season with is found to be the 120th day (June 28) of the planting season which starts on March 1. The last three decisions are discussed by Logan and are assumed to fit this application. The expected raw products are allocated as 33 percent for whole tomatoes, 50.67 percent for paste, and 16.37 percent for sauce. These allocations depend on the demand for these products and the contractual agreements made by the firm with it's customers. The order in which the processing lines are numbered reflects the priority with which the final products are produced as shown earlier in Table IV, and the number of shifts are stipulated at 1, 1.5, 2, 2.5, and 3 shifts for whole and processed products.

Processing Schedules and Costs

The results obtained from the model for a particular week are printed in table form. Weekly schedules show the various feasible cost alternatives for different shifts, the least cost alternative selected, the processing lines used to process the raw product for that week, the type and amount of final products produced by each canning line for the least cost alternative selected, the total costs for each input item, the average temperature expected to prevail over the fruit set period, the daily average whole and processed raw products, and total costs incurred for that week. If a frost occurs during the growing season or an costs incurred for that week. If a frost occurs during the growing season or an unfavorable daily average temperature occurs during the fruit set period, the model indicates that by printing out the week, the iteration number, and the day unfavorable temperature occurs and no schedule is printed for that week. Under this condition the firm shuts down for the week, unless there is a carryover of raw products from the previous week and no processing costs are incurred. Table XVII shows the type of results obtained for each week using week two of the first iteration as an example. The average daily temperature over the fruit set period is equal to 67.44 and the random yield generated is 8.4 tons per acre giving a total raw product (weekly arrival) of 3,361 tons divided into 1,109 tons for whole and 2,252 tons for processed products. This amount could be processed in one day if the processing lines are to work at full capacity operating at three shifts for whole and three shifts processed or in two days operating at two shifts each, but since the plant is assumed to work for a minimum of five days per week, the processing lines are operated for five days working one shift whole and one shift processed. In this week, given the small amount of raw product to be processed, all the production option combinations are feasible and the least cost alternative selected is number one with the lowest cost of $78,408 for labor and clean-up. Lines used are 1, 2, 3, 4, 5, 8, 9, and 10 as shown in the table along with the corresponding can size used, raw product equivalent processed by each line, and the production of final products in cases. The costs of each input item used in the processing operation are also illustrated in the table with total processing costs (TOTAL) of $871,357.75 for the week. The lower section of the table shows the fruit set period average daily temperature (° F), the number of days required by the plant to set fruits (Fruit Set Period) and the day of the season when it begins relative to

Table XVII. Processing Operations Schedule and Costs for Week 2 of Iteration One.

```
WEEK *    2  ITRTN *    1
TABLE: 2
DAYS WORKED: 5

 WEEKLY ARIVAL:   3361.  DAILY WHOLE:   222.   DAILY PROCESSED:   450.

      COST     *SHIFTS WHOLE   *SHIFTS PROCESSED
 1     78408       1.0              1.00
 2     90654       1.0              1.50
 3    104725       1.0              2.00
 4    118879       1.0              2.50
 5    122136       1.0              3.00
 6    107352       1.5              1.50
 7    121423       1.5              2.00
 8    135578       1.5              2.50
 9    139117       1.5              3.00
10    137050       2.0              2.00
11    151204       2.0              2.50
12    155027       2.0              3.00
13    168545       2.5              2.50
14    172652       2.5              3.00
15    197933       3.0              3.00

COST ALTERNATIVE SELECTED:  1
NUMBER OF EMPLOYEES PER SHIFT:    215      0      0

LINE  CAN SIZE a    CANS         XIJT         QIJT
 1        1       220635       167.13       9193.16
 2        1       283674       214.88      11819.77
 3        1       346713       262.64      14446.38
 4        3        31519       154.81       5253.23
 5        3        63038       309.63      10506.45
 8        3        63138       682.32      10523.13
 9        3        52615      1015.38       8769.29
10        4       517137       554.09      10773.69

LABOR          64193.61
CLEAN UP       14215.00
WATER           5247.56
GAS            43892.88
ELECTRICITY     4740.12
CARTON COSTS   12892.25
CAN COSTS     234215.12
LYE             3216.36
SALT            4147.95
TOMATOES      484597.62
TOTAL         871357.75

AVG DAILY TEMP:67.44  FRUIT SET PERIOD: 11   TIME *    75

ACRES:400.00  PLANTING DATE:  26  YIELD: 8.4022
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[a] Can Size 1 = 303, 2 = 2½, 3 = 10, 4 = 6 oz, and 5 = 12 oz.

March 1st, (TIME), acres planted, planting date, and yield obtained. To illustrate the difference in the results obtained from one week to another, Table XVIII presents the processing schedule for week seven of the same iteration. The amount of raw product processed this week is 8,797 tons, an increase of 5,436 tons from week one as a result of higher yields obtained at more favorable temperatures during the fruit set period. Only production options 10 through 15 are feasible for this week with the processing lines working at least two shifts per day for both whole and processed products. The lowest cost alternative selected is number ten and all processing costs have increased as more processing lines are used to process the raw products.

The weekly schedules for the season are printed out in a summary table at the end of each iteration as shown in Table XIX. The table presents the items included for each week's schedule as explained above plus the total of these items for the whole season.

Recall from Chapter I that one of the objectives of this study was to determine the impact that the stochastic temperatures have on the processing costs. The variability in the processing costs from one week to another is a result of the indirect effect of temperatures passed through yields. The weekly average processing costs and average tomato yields obtained from 80 replications of the processing season as well as the coefficient of variations are presented in Table XX. The coefficient of variation (C.V.) of a variable, estimated as the standard deviation divided by the mean and multiplied by 100 to express it as a percentage, can be used to measure the relative variability of the variable's distribution. It can be used also to compare the relative variabilities of different distributions since it is not expressed in any units. The average yields and processing costs obtained early and late in the season are

Table XVIII. Processing Operations Schedule and Costs for Week 7 of Iteration One.

```
WEEK *    7  ITRTN *    1
TABLE: 3
DAYS WORKED: 5

 WEEKLY ARIVAL:   8797.  DAILY WHOLE:   581.   DAILY PROCESSED:  1179.

     COST     *SHIFTS WHOLE  *SHIFTS PROCESSED
10   156087        2.0            2.00
11   170450        2.0            2.50
12   164025        2.0            3.00
13   185879        2.5            2.50
14   179166        2.5            3.00
15   197573        3.0            3.00

COST ALTERNATIVE SELECTED: 10
NUMBER OF EMPLOYEES PER SHIFT:   223   223     0

LINE  CAN SIZE[a]  CANS         XIJT       QIJT
 1         1      398743       302.05    16614.33
 2         1      512670       388.35    21361.27
 3         1      626597       474.65    26108.22
 4         3       56963       279.79     9493.89
 5         3      113926       559.57    18987.78
 6         2      159497       213.24     6645.73
 7         2      512670       685.43    21361.26
13         2      426167      1253.64    17756.97
14         4      994390      2398.72    20716.47
15         5      610839      1308.97    25451.64
16         4     1420556      1841.26    29594.93

LABOR         133862.37
CLEAN UP       22225.00
WATER          13735.65
GAS           106915.25
ELECTRICITY    12407.40
CARTON COSTS   34738.84
CAN COSTS     710025.69
LYE             8418.91
SALT           11058.86
TOMATOES      576567.81
TOTAL        1629955.00

AVG DAILY TEMP:75.14  FRUIT SET PERIOD: 10   TIME *  107

ACRES:400.00  PLANTING DATE:  58  YIELD:21.9930
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[a] Can Size 1 = 303, 2 = 2½, 3 = 10, 4 = 6 oz, and 5 = 12 oz.

Table XIX. Annual Production Schedules and Costs for Weeks 1-20 of Iteration 1.

ANNUAL AGGREGATE PRODUCTION PLAN FOR WEEK 1-13

WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13
DAYS WORKED	0	5	10	15	20	25	30	35	40	45	50	55	60
SHIFTS(WHOLE)	0	1	1	1	1	2	2	1	1	1	1	1	1
SHIFTS(PROCESS)	0	1	1	1	1	2	2	1	1	1	1	1	1
EMPLOYEES/SHIFT	0	215	223	223	225	223	223	225	223	225	217	223	223
RAW PRODUCT	0	3360	4605	4443	7329	7956	8797	7591	6928	5133	5296	7025	7164
PRODUCTION (CASES)													
LINE 1	0	9193	8697	8391	13841	15026	16614	14337	13084	9695	14487	13267	13531
LINE 2	0	11819	11182	10789	17796	19319	21361	18434	16823	12466	18626	17058	17397
LINE 3	0	14446	13666	13186	21751	23612	26108	22530	20561	15236	22765	20848	21263
LINE 4	0	5253	4969	4795	7909	8586	9493	8192	7476	5540	8278	7581	7732
LINE 5	0	10506	9939	9590	15818	17173	18987	16385	14953	11080	16556	15162	15464
LINE 6	0	0	3478	3356	5536	6010	6645	5735	5233	3878	0	5306	5412
LINE 7	0	0	11182	10789	17796	19319	21361	18434	16823	12466	0	17058	17397
LINE 8	0	10523	9295	8968	11272	16059	17756	11676	13984	7895	10690	14179	14461
LINE 9	0	8769	10844	10463	13150	18736	20716	13622	16315	9211	12472	16563	16872
LINE 10	0	10773	13323	12855	16156	23019	25451	16735	20044	11317	15322	20324	20728
LINE 11	0	0	15492	14947	18787	26766	29594	19460	23307	13159	17817	23633	24103
LINE 12	0	0	0	0	4696	0	0	4865	0	3289	0	0	0
AVG DAILY WHOLE	0	221	303	293	483	525	580	501	457	338	349	463	472
AVG DAILY PROC.	0	450	617	595	982	1066	1178	1017	928	687	709	941	960
COSTS (DOLLARS)													
LABOR	0	64193	66485	66485	101168	133862	133862	101168	100173	67145	97714	100173	100173
CLEAN UP	0	14215	22225	22225	23725	22225	22225	23725	22225	23725	22225	22225	22225
WATER	0	5247	7190	6937	11443	12422	13735	11853	10817	8015	8269	10968	11186
GAS	0	43892	55967	54000	89072	96696	106915	92264	84201	62393	64367	85377	87076
ELECTRICITY	0	4740	6494	6266	10336	11221	12407	10707	9771	7240	7469	9907	10105
CARTONS	0	12892	18184	17545	27867	31418	34738	28865	27358	19520	20632	27740	28292
CANS	0	234215	371678	358619	541226	642166	710025	560622	559182	379118	421227	566994	578273
LYE	0	3216	4407	4252	7013	7614	8418	7265	6630	4913	5068	6722	6856
SALT	0	4147	5789	5585	9213	10001	11058	9543	8709	6453	6536	144457	9006
TOMATOES	0	484597	633816	291212	480346	521463	576567	497560	454077	336473	347118	460421	469579
TOTAL	0	871357	1192238	833131	1301412	1489092	1629955	1343575	1283146	914999	1000629	1299363	1322775
ACRES NEEDED	400	400	400	400	400	400	400	400	400	400	400	400	400
PLANTING DAY	18	27	33	41	46	53	59	66	73	80	87	93	100

Table XIX. (continued)

ANNUAL AGGREGATE PRODUCTION PLAN FOR WEEK 14-20

WEEKS	14	15	16	17	18	19	20	TOTAL
DAYS WORKED	65	70	75	80	85	90	90	90
SHIFTS(WHOLE)	1	1	1	1	1	2	0	NA
SHIFTS(PROCESS)	1	1	1	1	1	2	0	NA
EMPLOYEES/SHIFT	223	223	220	220	225	223	0	NA
RAW PRODUCT	6287	7136	5735	5771	5159	9494	0	400
PRODUCTION (CASES)								
LINE 1	11874	13478	14179	14269	9743	17931	0	231645
LINE 2	15267	17329	18230	18346	12527	23054	0	297829
LINE 3	18660	21181	22282	22423	15311	28177	0	364014
LINE 4	6785	7702	8102	8153	5567	10246	0	132368
LINE 5	13571	15404	16205	16307	11135	20492	0	264737
LINE 6	4749	5391	5671	5707	3897	7172	0	83186
LINE 7	15267	17329	0	0	12527	23054	0	230806
LINE 8	12691	14405	11576	11649	7934	19164	0	224188
LINE 9	14806	16806	13506	13591	9257	22358	0	253045
LINE 10	18191	20648	16593	16698	11373	27469	0	317026
LINE 11	21152	24009	19294	19416	13224	31940	0	356108
LINE 12	0	0	0	0	3306	0	0	16158
AVG DAILY WHOLE	414	471	378	380	340	626	0	NA
AVG DAILY PROC.	842	956	768	773	691	1272	0	NA
COSTS (DOLLARS)								
LABOR	100173	100173	98944	98944	67145	133862	0	1731848
CLEAN UP	22225	22225	22225	22225	23725	22225	0	398040
WATER	9817	11143	8954	9011	8055	14824	0	179895
GAS	76415	86738	69702	70144	62700	115390	0	1403316
ELECTRICITY	8867	10065	8088	8140	7276	13390	0	162499
CARTONS	24828	28182	22437	22579	19616	37492	0	450196
CANS	507475	576029	458240	461142	380985	766308	0	9073525
LYE	6017	6830	5488	5523	4937	9086	0	110262
SALT	7904	8971	7119	7164	6485	11935	0	0
TOMATOES	412089	467758	375890	378271	338130	622271	0	8147639
TOTAL	1175813	1318118	1077092	1083146	919057	1746786	0	21801664
ACRES NEEDED	400	400	400	400	400	400	400	8000
PLANTING DAY	107	113	120	126	133	140	146	NA

Table XX. Average Tomato Yields, Average Processing Costs and their Coefficient of Variations for Each Week of the Season.

	Tomato Yields		Processing Costs	
Week#	Average	C.V.	Average	C.V.
1	0.53	442.8	404,084	135.1
2	4.22	136.6	962,746	64.1
3	11.24	63.3	1,418,074	39.8
4	17.28	35.7	1,347,686	26.5
5	19.73	17.8	1,448,515	18.0
6	20.31	13.4	1,491,738	13.3
7	20.70	13.2	1,513,510	12.8
8	20.42	14.9	1,494,581	14.1
9	18.49	17.6	1,360,584	16.5
10	16.18	17.0	1,204,161	16.0
11	16.24	14.4	1,208,513	13.9
12	14.88	11.8	1,116,296.	11.5
13	14.79	15.8	1,107,670	15.9
14	14.61	16.2	1,094,565	15.9
15	15.48	14.5	1,158,509	14.0
16	15.83	12.8	1,182,230	11.8
17	15.39	20.4	1,148,811	19.9
18	16.48	30.7	1,220,856	29.7
19	19.46	54.5	1,133,682	54.0
20	6.17	155.4	473,848	150.9

associated with high C.V. This suggests that processing operations during these times of the season can be highly risky. The risk of yield reduction and/or plant damage caused by adverse temperatures early and late in the season is carried over to the processing facilities and resulted in a high variability of processing costs.

The pattern of the weekly average processing costs is illustrated graphically by Figure 11. The processing cost curve shows that early in the season, when the probability of frosts are high and/or temperatures are low during the fruit set period, processing costs are low. As the season progresses, the curve rises up indicating higher costs due to higher yields that resulted from more favorable temperatures during the fruit set stage. The curve reaches the peak at the average processing cost of about $1.5 million when temperatures are ideal and consequently per acre yields are the highest. The curve then declines as lower yields are obtained due to high temperatures during the fruit set period and/or frosts late in the season.

Tomato Yields

Tomato yields are generated from triangular probability distributions conditional on the average temperature during the fruit set stage of the tomato plant. When the temperatures is low (65° to 69°F) during this stage, most of the fruits are not expected to set and hence the expected per acre tomato yield will be low. As temperatures rises, yields will increase up to a certain level then declines as temperature rises above the maximum threshold of 80°F beyond which fruit set will be reduced. If frosts occur, the tomato plant will be damaged and yields will be zero or too low to be considered. As shown earlier in Table XX, the coefficient of variation for the first and last few weeks are very high

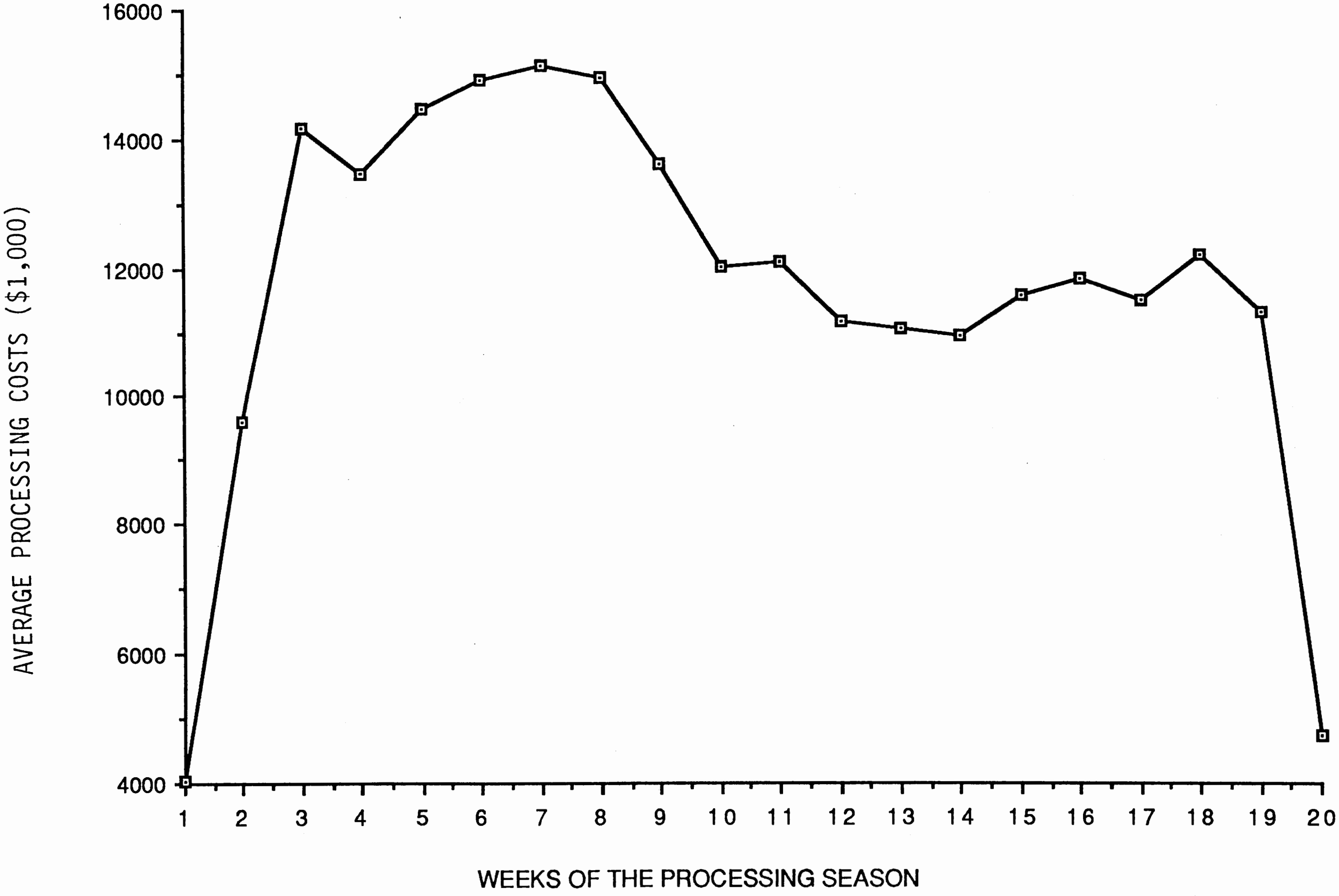

Figure 11. Weekly Average Processing Costs ($1,000) for 80 Iterations.

indicating that the distribution of tomato yields during these weeks varies widely as a result of the hostile temperatures. Figure 12 illustrates the distribution of per acre average tomato yields obtained from 80 iterations of each week of the processing season.

The impact of stochastic temperature on the flow of raw products to the processing firm is realized when harvesting and hence processing starts. To determine the probability of achieving various levels of yields during a certain harvesting date, cumulative probabilities for tomato yields conditional on the harvesting date are derived. Figure 13 graphically presents these distributions for selected harvesting dates.

Planting Dates and Fruit Set Period

The model developed for this application is designed to predict stages of tomato plant growth. Of importance to this study are the planting stage and fruit set stage. To predict each stage, the method employed requires the amount of heat units needed by the plant to develop the stage and the expected harvest date. Since data are not available, assumptions were made about the heat units and harvesting dates, as discussed earlier in Chapter III, to simulate the fruit set and planting dates. The means of 80 replications of these two variables, as well as their standard deviations are presented in Table XXI.

Expected Profits

The firm's performance is measured by several interrelated factors which include profitability, capital position, cash flow adequacy, size, and productivity and efficiency. In this application, only profitability is considered. Several methods have been developed to measure the profitability of a business firm.

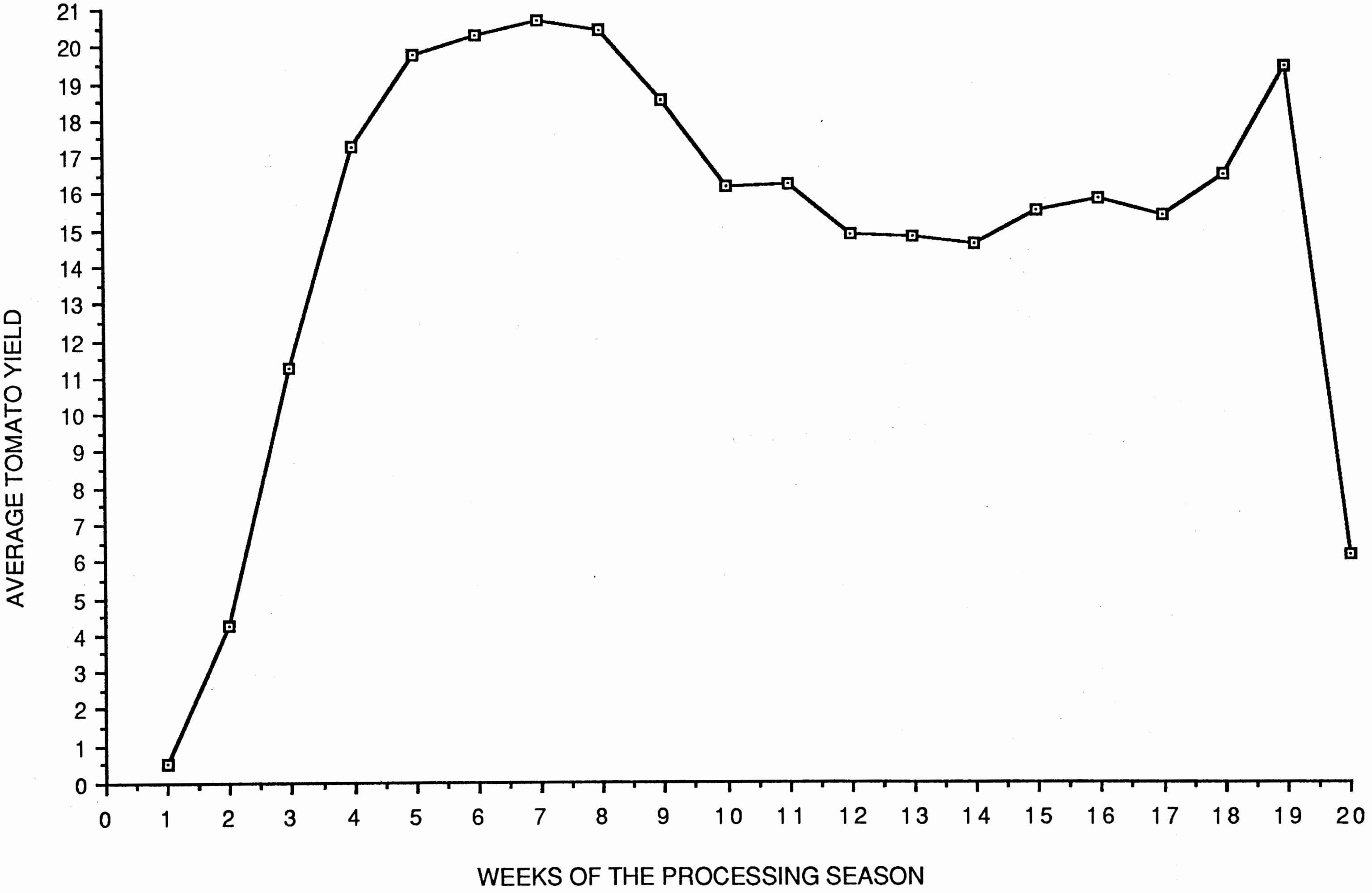

Figure 12. Weekly Average Tomato Yields (Tons/Acre) for 80 Iterations

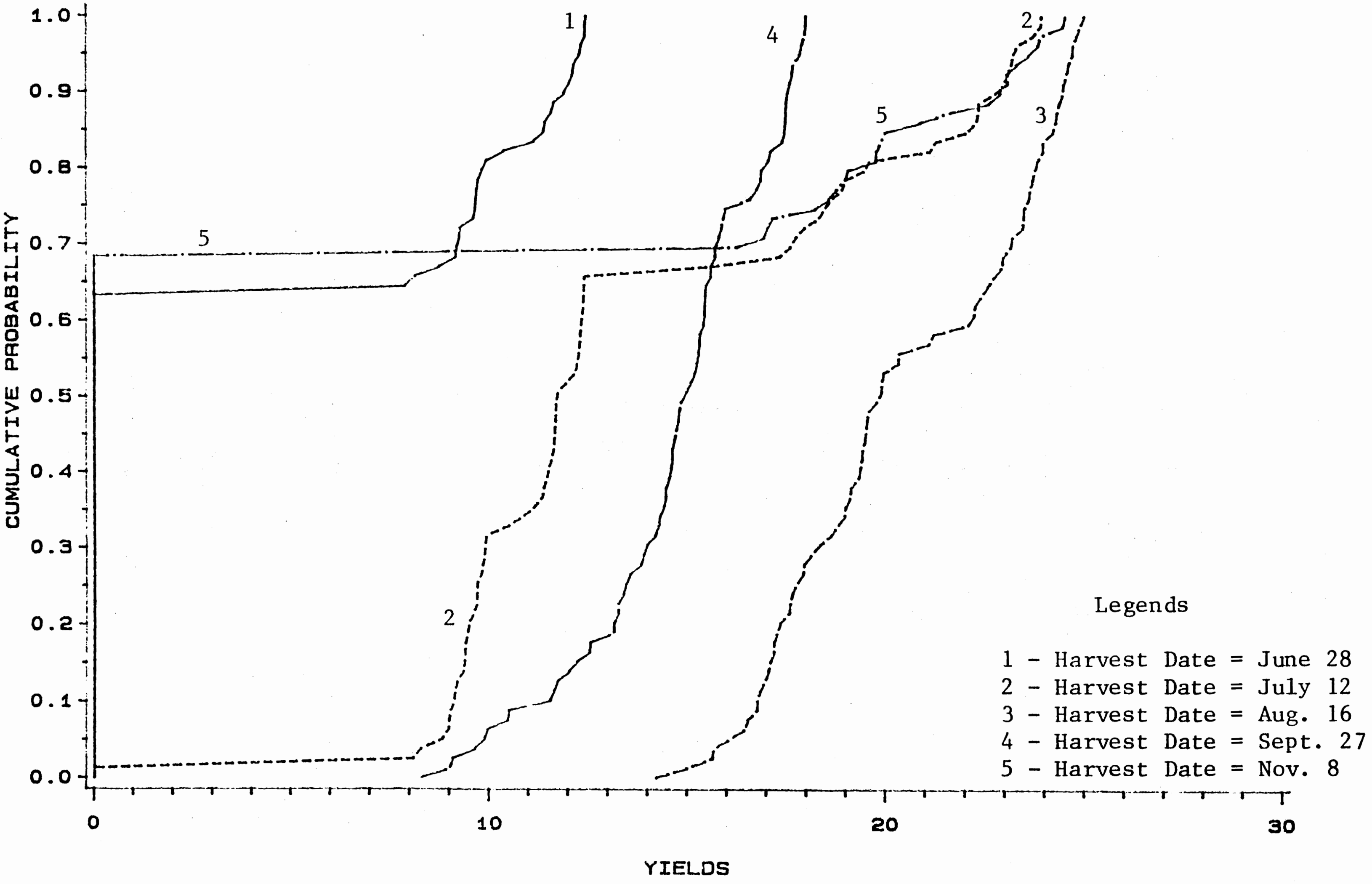

Figure 13. Cumulative Probability Distributions for Tomato Yields Conditional on the Harvesting Dates.

Table XXI. Means and Standard Deviations of Simulated Planting Dates and Fruit Set Dates by Harvest Date.

Harvesting Date Day of the Growing Season	Day of the Year	Planting Date Mean	Planting Date Standard Deviation	Fruit Set Date Mean	Fruit Set Date Standard Deviation
120	June 28	Mar. 16	1.061	May 7	1.000
127	July 5	Mar. 23	1.212	May 14	0.889
134	July 12	Mar. 30	1.097	May 20	1.214
141	July 19	April 6	1.273	May 27	1.067
148	July 26	April 13	1.227	June 3	0.929
155	Aug. 2	April 20	1.158	June 9	1.049
162	Aug. 9	April 27	1.153	June 16	0.922
169	Aug. 16	May 5	1.085	June 23	0.829
176	Aug. 23	May 11	1.383	June 29	1.112
183	Aug. 30	May 18	1.268	July 6	0.987
190	Sept. 6	May 25	1.180	July 13	1.140
197	Sept. 13	June 1	1.000	July 20	1.101
204	Sept. 20	June 7	1.378	July 27	1.313
211	Sept. 27	June 14	1.227	Aug. 3	1.318
218	Oct. 4	June 21	1.125	Aug. 10	1.260
225	Oct. 11	June 27	1.432	Aug. 17	1.240
232	Oct. 18	July 4	1.302	Aug. 24	1.095
239	Oct. 25	July 11	1.302	Aug. 31	1.095
246	Nov. 1	July 18	1.217	Sept. 7	1.090
253	Nov. 8	July 25	1.248	Sept. 14	1.157

The two most common measures are net income (profits) and returns to equity capital. Net income, with which this analysis is concerned, is defined as the difference between the firm's total revenues and total costs excluding taxes and insurance which can be written as

$$\pi = TR - TC$$

where: π = profits, TR = total revenue, TC = total cost.

Total revenue of the firm was calculated as the sum of the number of cases produced by each processing line during the season multiplied by their respective unit price for the different types of final products. Fixed costs of the processing facility were amortized as discussed in Chapter III to estimate the annual fixed costs and were added to the variable processing cost to determine the total processing costs incurred during the season. Therefore, profits or net income of the firm can be written as

$$\pi = \sum_i Q_i P_i - \left(\sum_j \sum_i N_i C_i + FC \right)$$

where, Q_i is the total amount of final product produced by line i, P_i is the price per case, and FC is the fixed costs. The term $\sum N_i C_i$ is the variable costs as explained earlier, summed over the number of weeks (j).

To determine the probabilities of various levels of profits based on the assumptions used to build the model, the results obtained were plotted as a cumulative probability, Figure 14. The average expected pre-tax profits obtained from 80 replications is about $4.2 million with a coefficient of variation of 16.6. The results suggest that if the total costs estimated reflect the true costs and that prices for the final products will remain unchanged, the firm can make pre-tax profits given the unexpected changes in temperatures. Whether $4.2 million is enough to pay taxes, insurance, and leave enough return on investment must be decided by potential investors.

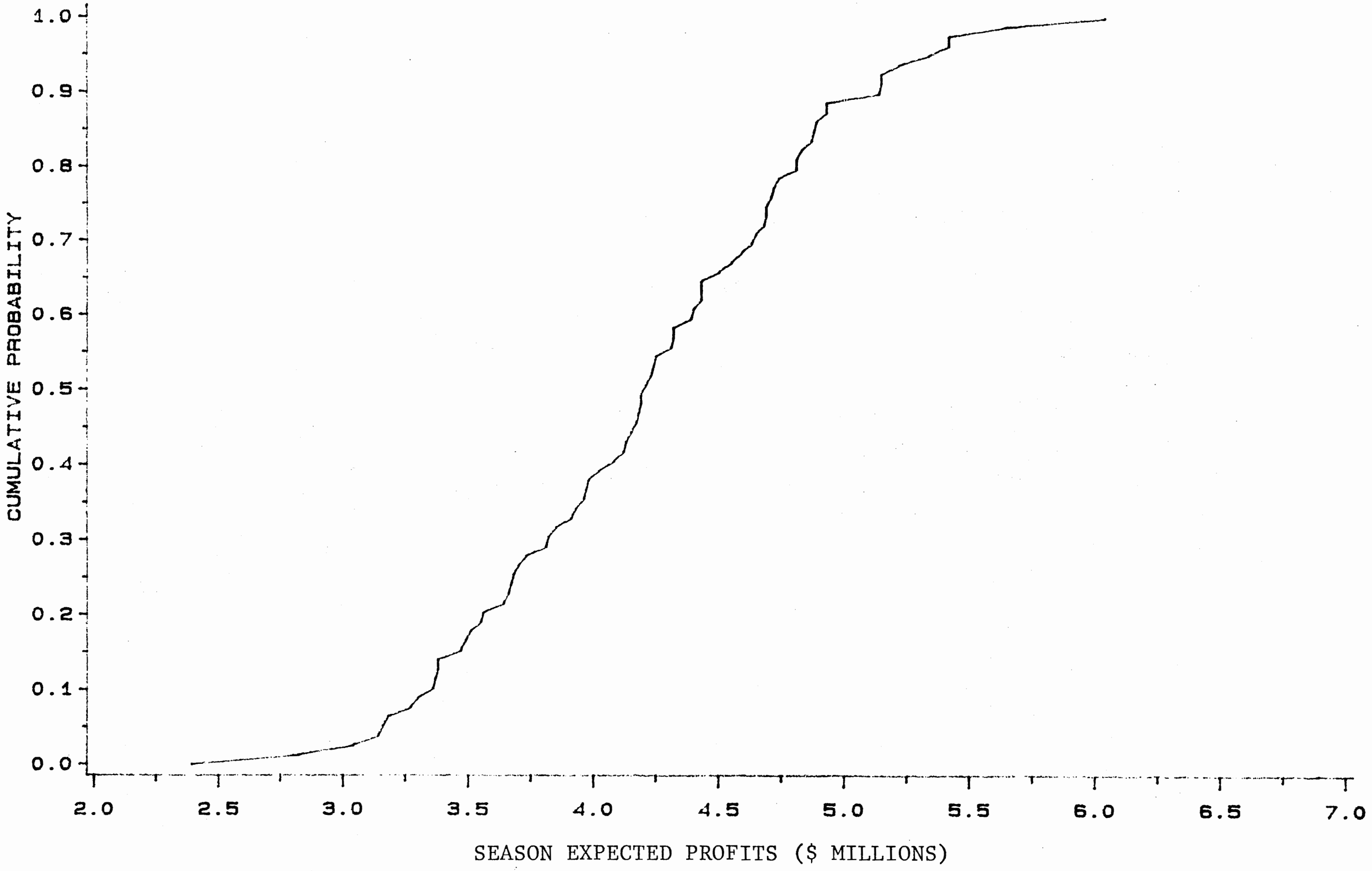

Figure 14. The Cumulative Probability Distribution of Profits from 80 Iterations.

Alternative Scenarios

The model discussed so far in this study is based on operating specifications for an existing California tomato processing firm with a given number of processing lines at a given rated capacity and a fixed combination of final products. Operating at full capacity, the firm can process more than 129.4 tons of raw products per hour at 70 percent efficiency.

The results obtained for this application, with an initial specification of 400 acres per week (8,000 acres for the season) for raw tomato production, show that the processing lines are operating at less than full capacity and some of them were not used when generated yields were low. Specification of a smaller processing firm may be more realistic since the processing tomato crop is new to the area and inexperienced farmers may not be willing to grow the 8,000 acres of new crop, especially if a high yield risk is associated with it as discussed earlier. The outcome of the model suggested the need to look at alternative scenarios. This section presents two alternative scenarios in which the number of processing lines and the number of acres planted are reduced. In the first alternative scenario, the processing lines are reduced to only four lines (lines 5, 7, 8, and 12 from Table IV) and the number of acres is reduced to 200 acres per week (4,000 acres for the season). The second alternative scenario considers the possibility this number of acres may still be unobtainable and considers only 100 acres per week (2,000 acres for the season). The processing lines were chosen to allow the firm to concentrate on institutional can sizes.

Results and Comparison of the Two Alternative Scenarios

The input data and assumptions used to run the model under these two scenarios are consistent with the base model except for the number of processing lines, the annual estimated fixed costs, and the number of acres planted for tomatoes as discussed above. Annual fixed costs for the two alternative scenarios are estimated at $2,473,672 which include all the items specified earlier for the base model but at levels consistent with the four processing lines chosen for these two scenarios.

The results obtained from the model under these two scenarios could be analyzed in terms of the weekly per ton processing costs and the expected profits generated under the seasonal variations in temperatures. The average per ton processing costs for each week of the simulated season for both scenarios, their coefficient of variations are presented in Table XXII along with the per ton processing costs and the coefficients of variation obtained from the base model to allow further comparisons relative to the firm's size. Given the amount of raw products obtained from 200 acres each week, average processing costs for each week are generally lower than those when 100 acres are used to obtain the raw products with the same number of processing lines. Even though it may be unrealistic, the base model produced lower average processing costs at any given week of the season.

The expected profits generated for each simulated season are presented as cumulative probability distributions in Figures 15 and 16 for the first and second alternative scenario, respectively. The figures indicate that under the 200 acre scenarios the profitability of making less than $1.23 million of pre-tax profits is zero, while under the 100 acre scenario the probability of making less than zero profits is about 0.90. The results suggest that in order to establish the

Table XXII. Average Weekly Processing Costs Per Ton of Processed Raw Products and Their Coefficient of Variations for the Base Model and the Two Alternative Scenarios.[a]

Week No.	Base Model Processing Costs	 Coefficient of Variation	200 Acre Scenario Processing Costs	 Coefficient of Variation	100 Acre Scenario Processing Costs	 Coefficient of Variation
	$/ton		$/ton		$/ton	
1	263.27	80.35	303.55	80.35	319.79	80.35
2	263.45	47.75	292.85	47.80	318.38	47.82
3	257.51	15.99	283.28	16.17	305.68	16.46
4	184.06	1.92	204.73	3.24	223.03	6.46
5	183.15	2.05	203.05	2.54	219.41	4.49
6	183.26	1.99	202.26	1.79	217.71	3.02
7	182.48	2.24	201.73	1.67	216.59	2.98
8	182.74	2.25	202.02	1.78	217.06	2.92
9	183.84	2.44	203.66	1.80	219.78	3.42
10	185.70	1.74	205.87	1.98	224.32	3.42
11	185.58	1.59	206.20	1.88	224.45	3.33
12	187.02	1.12	207.43	1.94	227.01	3.08
13	186.56	1.28	208.08	2.55	227.94	3.77
14	186.68	1.26	208.11	2.13	229.15	3.87
15	186.53	1.07	206.86	1.58	226.50	3.67
16	186.32	1.36	206.31	1.59	224.96	2.91
17	186.17	15.97	206.18	15.98	224.72	16.26
18	186.17	22.58	205.06	22.60	222.44	22.78
19	183.12	45.05	203.04	45.04	219.27	45.11
20	183.02	83.45	201.91	83.44	217.15	83.45

[a] The weeks within the iterations where no yields were obtained are not included in the computations of these figures.

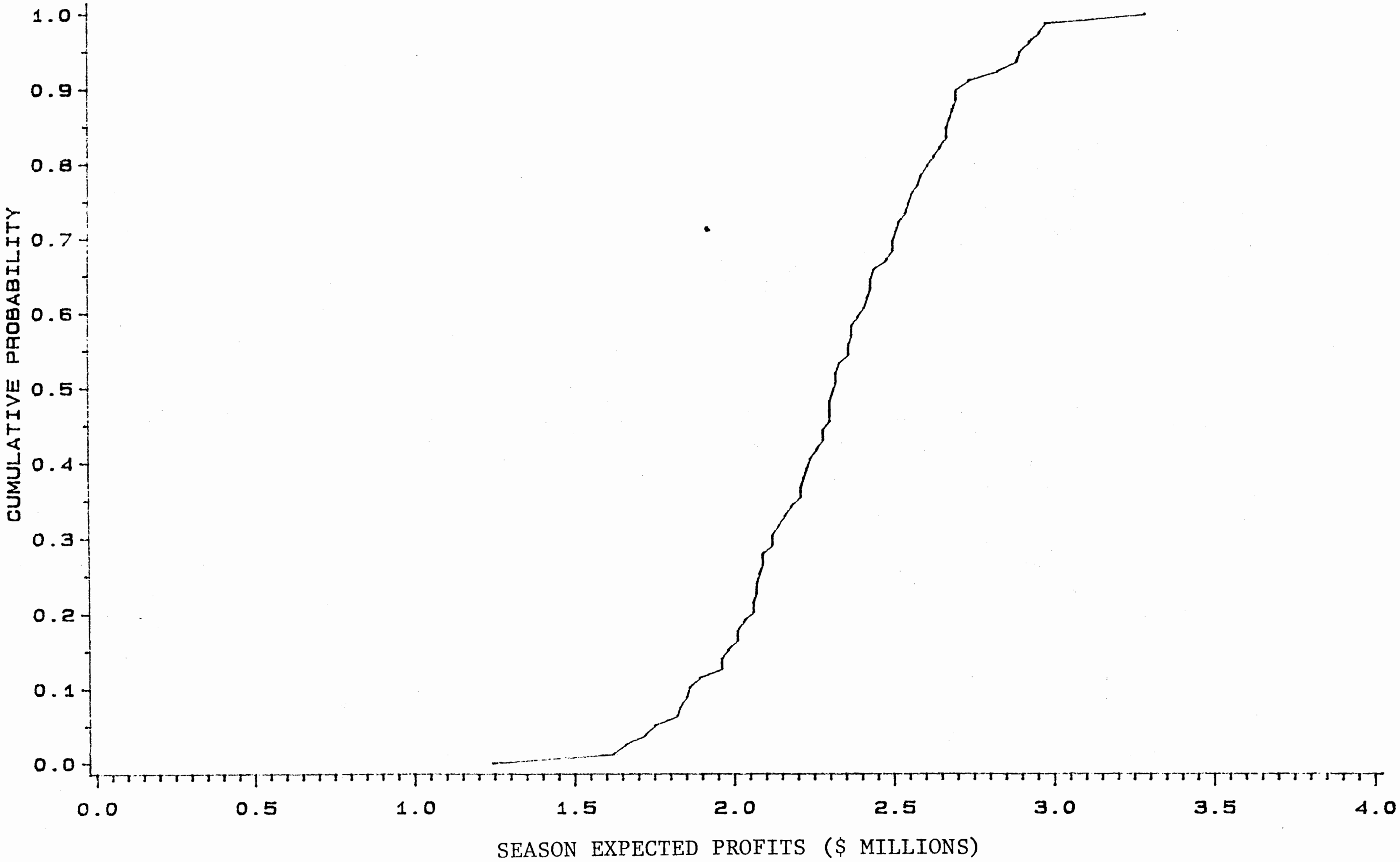

Figure 15. The Cumulative Probability Distribution of Expected Profits for the 200 Acre Scenario.

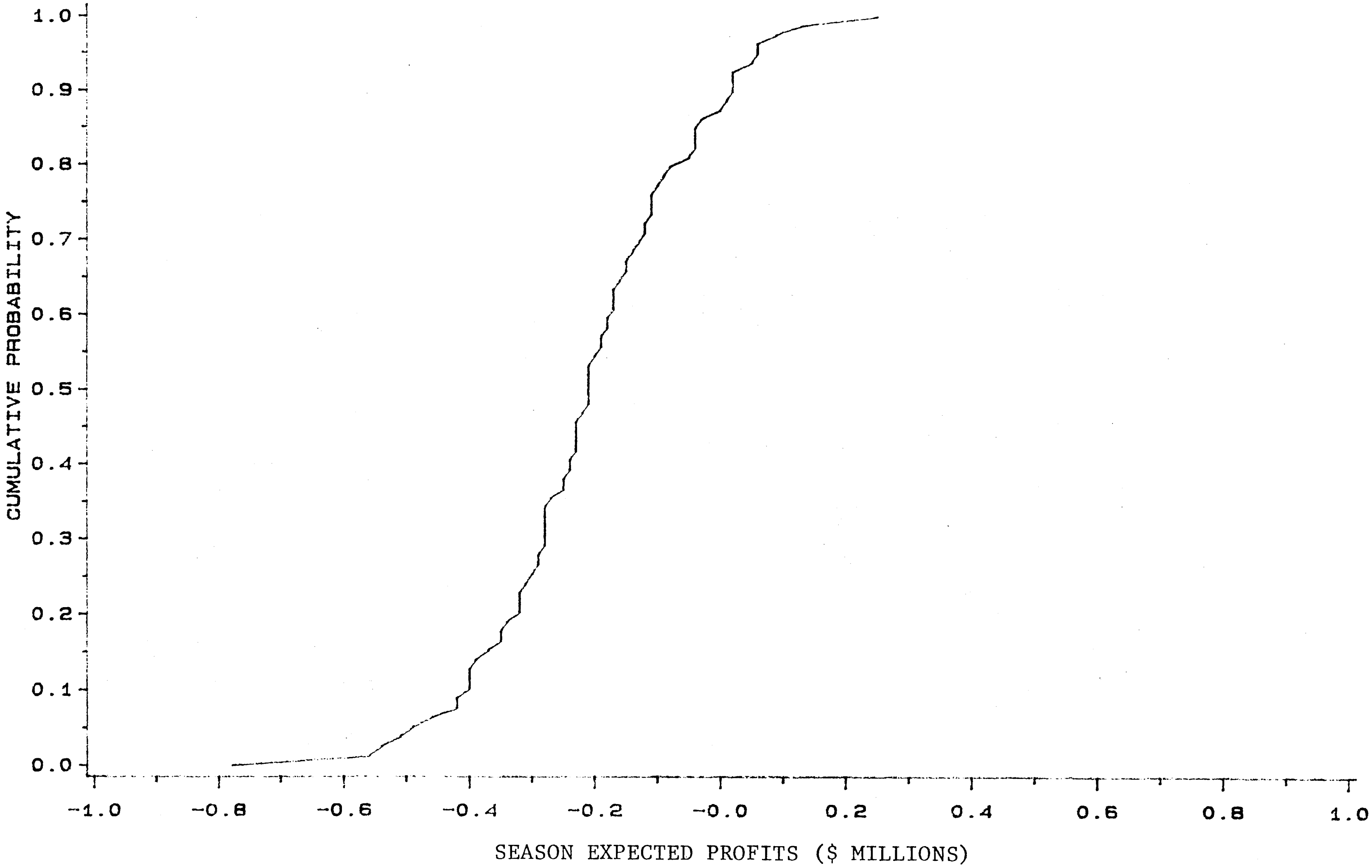

Figure 16. The Cumulative Probability Distribution of Expected Profits for the 100 Acre Scenario.

investment, the number of acres devoted to raw product production should be greater than 100 acres under the proposed number of processing lines.

CHAPTER V

SUMMARY AND CONCLUSIONS

With the declining returns from the traditional crops in the southeastern part of Oklahoma, farmers are more eager to consider alternative crops to improve their incomes. Vegetables have been considered as potential alternative crops and the growing conditions in the area are favorable. With the increased interest in vegetable production, vegetable processing came into consideration as a potential market and a chance for improving the agricultural sector in the area. Vegetable processing requires an uniform flow of raw products to the processing plant which could be hampered by the unpredictable weather changes.

Establishment of a vegetable processing industry in the area could be faced with the uncertainty of the raw product availability when the processing season starts due to unpredictable weather changes. Also firms may face the uncertainty about the acreage required to supply the plant with the raw products as most vegetable crops are associated with high production risks which may drive the new farmers away from producing the crops.

Tomatoes for processing have been considered in this study to analyze the effect of the uncertain temperature changes on the costs of processing tomatoes in the study area and to estimate the possibility that an established processing firm would make profits given the stochastic temperatures and yields, and the available raw product acreages.

The methodology chosen, with which to analyze the effect of stochastic tomato yields caused by the unpredictable temperature variation on the costs of tomato processing operation, was simulation analysis. A stochastic simulation model, explained in Chapter III, was developed based on a simulation model available from California. The basic structure of the model is depicted by the flow chart of Figure 3 in Chapter III.

The model was designed to find the least cost combination in terms of the rates and processing time of various levels of output, given the amount of raw products available during each week of the processing season. To estimate the weekly flow of raw products to the firm, tomato yields were generated stochastically from triangular probability distributions conditional on the average daily stochastic temperatures during the fruit set stage of the tomato plant growth. Stochastic temperatures were drawn randomly from empirical probability distributions using 33 years of historical data. The planning schedule for the season was simulated 80 times to determine the probabilities and the expected values of the yield, the processing costs, and the profits.

The results obtained from 80 iterations of the processing season, which consists of 20 weeks, were used to validate the model. Stochastic temperatures generated were tested statistically and described graphically to compare them with the historical data, and were found to have satisfactory results. The means and standard deviation of the daily temperatures were tested using the t-test, and the correlation coefficients for the estimated temperatures were estimated and compared to those of the actual data. Stochastic yields generated from conditional subjective triangular probability distributions were plotted as cumulative distributions for particular temperature ranges and harvesting dates. Processing schedules produced by the model depicted the number of days worked, the number of processing lines and their levels of production of final products, processing operation costs, per acre yield, planting date, and the fruit set period and time for each week of the 20-week processing season.

The results obtained were analyzed in terms of the variability of processing costs caused by the stochastic temperatures through their impact on yields. The coefficient of variation was used to measure this variability which indicated that early and late in the season yields and hence processing costs were highly variable. The average expected profit for the season was estimated at about $4.2 million with a coefficient of variation of 16.6. This estimate was based on the assumptions that no variable costs are incurred when no raw products were delivered due to adverse temperatures and that labor was available on a call basis. If these assumptions do not hold expected profits could be more variable as temperatures vary from one season to another. The expected profits obtained from 80 iterations of the season were plotted as a cumulative probability distribution in Figure 14.

Given the amount of heat units required by the tomato plant to reach certain stages of growth and the harvest date, the model used the heat unit concept to estimate tomato yields, planting dates, and fruit set period. The fruit set period's duration were estimated at 10 or 11 days and appeared to be quite inconsistent with the time of the season the fruit were set, since the period durations were expected to have wider ranges as temperatures cool off early and late in the season, and as they get too hot in mid-season. This suggested that the method used (the corrected mean method) could not predict the periods accurately, because temperatures higher than the ceiling were not considered which may lead to plant growth and therefore longer fruit set periods.

Because the model was based on specifications for an existing California processing firm, acres devoted to raw tomato production were set initially at 400 per week (8,000 acres for the season) to see if the specified firm would be adopted to the study area. The results obtained, as explained in Chapter IV, suggested the need for alternative scenarios. Therefore, the model was run again under two alternative scenarios in which the size of the firm and the number of acres were reduced. The outcomes of the model under the two scenarios were discussed in Chapter IV. The first alternative scenario consisted of 4 processing lines and 200 acres per week (4,000 acres for the season), and the second scenario consisted of the same processing lines but with only 100 acres per week (2,000 acres for the season). The results indicated that the first alternative scenario had lower costs per ton of processed raw products and was more profitable when compared with the second alternative scenario which had a slim probability of making small returns. Costs per ton were higher and profits lower than when the firm contained 12 processing lines and 400 acres per week. Decisions on whether the plant is profitable enough must be made by potential investors.

Limitations and Suggestions for Further Research

The main limitation for this study was the availability of data regarding tomato yields for a specific cultivar, heat units required by the plant for various developmental growth stages, and harvesting and/or planting dates. The application of this model was based on assumptions considered as appropriate for Oklahoma which may not be applicable for other areas, hence careful assumptions should be taken for other locational studies. The model can be modified further to accommodate more environmental factors affecting processing plant operations and time value.

The model can also be modified to include different or mixed commodities for processing to make it more diverse. Input data like raw tomato prices and final product prices could be generated stochastically from specified probabilistic distributions to reflect real world behavior.

Another limitation imposed on the study was the use of the corrected mean method for heat unit calculations. It was favored to other methods because of the availability of some data required as inputs for the method assumed to fit this application. Experimentation with the model using the Sine function method was carried out assuming the same heat unit requirements used for the corrected mean method. These results gave a five days range in the fruit set period when plantings start early and late in the season. As discussed in Chapter III, the Sine function method has the capability of estimating the heat units considering the negative effect of too high temperatures which leads to plant development delay. Collection of tomato yield data and heat units from experimental plots in Oklahoma would allow application of the Sine function method.

Finally, this study only considered a simple measure of profitability. Before undertaking the establishment of a processing plant, investors would probably want to do a cash flow and capital budgeting analysis.

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APPENDICES

APPENDIX A

LABOR REQUIREMENTS AND HOURLY WAGES

Table XXIII. Labor Requirements for Sequential Use of Tomato Processing Lines.

Stage	Labor Class	Labor Option A No. of Employees	Labor Option M No. of Employees
I. Receiving & general preparation			
Supervisor	1	1	1
Weigh master	2	1	1
Janitor/cleanup	3	2	2
Crew leader	4	1	1
Bulk dumping worker	5	2	1
Lift driver	6	1	1
Flume control operator	7	2	1
Trash sorter	8	28	8
II. Preparation--whole tomatoes			
Supervisor	9	1	0
Sorter	10	38	0
Crew leader	11	1	0
Lye peel operator	12	1	0
Janitor/cleanup	13	2	0
Ingredient supplier	14	1	0
Merry-go-round	15	1	0
III. Preparation--products			
Supervisor	16	0	2
Pan operator	17	0	2
Cook's helper	18	0	1
Hot break worker	19	0	1
Finisher	20	0	1
Sauce blender	21	0	1
Janitor	22	0	1
Sorter	23	0	4
IV. Filling and processing--products			
Products supervisor	24	0	1
Depalletizer	25	0	3
Can Chaser	26	0	1
Seamer operator	27	0	1
Sterilizer	28	0	1
Janitor	29	0	1
V. Filling and processing--whole			
Filler	30	15	0
Crew leader	31	1	0
Seamer operator	32	1	0
Depalletizer	33	4	0
Can chaser	34	2	0
Empty can lift transporter	35	1	0
Janitor	36	2	0
VI. General processing			
Cook room supervisor	37	1	1
Seamer mechanic	38	1	1
Seam checker	39	2	1
Janitor	40	1	1
Die setter	41	1	1

Table XXIII. (continued)

	Greaser	42	1	1
	Lid trucker	43	1	1
	Red light hopper	44	1	0
	Empty can shrouds	45	1	1
	Cooker mechanic	46	1	0
	Switchman	47	1	1
	Empty can supplier	48	1	1
VII.	General service			
	Supervisor	49	0	0
	Boiler operator	51	1	1
	Electrician	52	1	1
	Cooking tower worker	53	1	1
	Line mechanic	54	4	1
	Sanitation worker	55	1	1
	Janitor	56	2	2
	Personnel clerk	57	1	1
	Time keeper	58	1	1
	Nurse	59	1	1
	Quality control supervisor	60	1	3
	Oiler/greaser	62	1	1
	Screening plant worker	63	1	1
	Payroll clerk	64	1	1
VIII.	New can stacking			
	Supervisor	65	1	1
	Stock checker	66	1	1
	Palletizer	67	7	4
	Hand fork truck operator	68	10	0
	Lift truck operator	69	2	1
	Transport train operator	70	1	1
	Mechanic	71	2	2
	Mechanic's helper	72	1	0
	Cleanup worker	73	1	1
	Pack accounting clerk	74	1	0
	Stretch wrap worker	75	2	1
IX.	Cooling floor			
	Stock checker	76	1	1
	Lift truck operator	77	2	1
X.	Pack receiving			
	Stock checker	78	1	1
	Lift truck operator	79	4	2

Given LO(A), then LO(B) = LO(A) + 1 employee #8 + 1 #10 + 1 #32. Given LO(A), then LO(C) = LO(A) + 2 employee #8 + 2 #10 + 2 #32. Given LO(A), then LO(D) = LO(A) + 3 employee #8 + 4 #10 + 3 #32. Given LO(A), then LO(E) = LO(A) + 4 employee #8 + 6 #10 + 4 #32. Given LO(A), then LO(F) = LO(A) + 5 employee #8 + 7 #10 + 5 #32. Given LO(A), then LO(G) = LO(A) + 6 employee #8 + 8 #10 + 6 #32.

Table XXIII. (continued)

The following processed products labor options are added to the option selected from the set LO(A) through LO(G). LO(H) adds 3 employee #8; 2 #16; 2 #17; 1 #18; 1 #19; 1 #20; 1 #21; 1 #22; 4 #23; 1 #24; 3 #25; 1 #26; 1 #27; 1 #28; and 1 #29. Given LO(H), then LO(I) = LO(H) + 1 employee #27. Given LO(H), then LO(J) = LO(H) + 2 employee #27. Given LO(H), then LO(K) = LO(H) + 3 employee #27 + 1 #68. Given LO(H), then LO(L) = LO(H) + 4 employee #27 + 2 #68.

Given LO(M), then LO(N) = LO(M) + 1 employee #27. Given LO(M), then LO(O) = LO(M) + 2 employee #27. Given LO(M), then LO(P) = LO(M) + 3 employee #27. Given LO(M), then LO(Q) = LO(M) + 4 employee #27.

Source: Logan (1984).

Table XXIV. Hourly Wages for Different Classes in Each Stage of the Processing Operations.

Stage & work classification [a] for the processing plant operations	Work classification [b] substitute in terms of occupation and/or wage (McAlester area)	$/Hour
Stage I. Receiving & General Preparation		
1. Supervisor	Warehouse supervisor	$10.41
2. Weigh master	Shipping & receiving clerk	4.24
3. Janitor/cleanup	Janitor, cleaners	4.45
4. Crew leader	General maintenance	6.04
5. Bulk dumping worker	Trucker: hands	4.75
6. Lift driver	Trucker, local haul	6.19
7. Flume control operator	General maintenance	6.04
8. Trash sorter	Cleaner	4.45
Stage II. Preparation--whole tomatoes		
9. Supervisor	Warehouse supervisor	10.41
10. Sorter	Cleaner	4.45
11. Crew leader	General maintenance	6.04
12. Lye peel operator	General repair, maintenance	6.04
13. Janitor/cleanup	Janitor/cleaner	4.45
14. Ingredient supplies	Stock handler	5.20
15. Merry-go-round	Tellers, all around	3.88
Stage III. Preparation products		
16. Supervisor	Warehouse supervisor	10.41
17. Pan operator	Warehouse supervisor	10.41
18. Cook's helper	General maintenance repairs	6.04
19. Hot break worker	General maintenance	6.04
20. Finisher	Stock handler	5.20
21. Sauce blender	Cleaner	4.45
22. Janitor	Janitor	4.45
23. Sorter	Cleaner	4.45
Stage IV. Filling and processing products		
24. Products supervisor	Warehouse supervisor	10.41
25. Depalletizer	Stock handler	5.20
26. Can chaser	Cleaners	4.45
27. Seamer operator	Maintenance, repairs	6.04
28. Sterilizer	Stock handler	5.20
29. Janitor	Janitor	4.45
Stage V. Filling and processing whole		
30. Filler	Porters, clears	4.45
31. Crew leader	General maintenance	6.04

Table XXIV. (continued)

32. Seamer operator	Stock handler	5.20
33. Depalletizer	Stock handler	5.20
34. Can chaser	Cleaners	4.45
35. Empty can lifter	Porter	4.45
36. Janitor	Janitor	4.45

Stage VI. General processing

37. Cook room supervisor	Warehouse supervisor	10.41
38. Seamer mechanic	Mechanics	10.97
39. Seam checker	Stock handler	5.20
40. Janitor	Janitor	4.45
41. Die setter	Stock handler	5.20
42. Greaser	Auto maintenance	7.83
43. Lid trucker	Truckers, local haul	6.19
44. Red light hopper	Maintenance, repairs, general	6.04
45. Empty can shrouds	Cleaners	4.45
46. Cooker mechanics	Mechanics, maintenance	10.97
47. Switchman	Janitors	4.45
48. Empty can supplier	Porter	4.45

Stage VII. General services

49. Supervisor	Warehouse supervisor	10.41
50. Supervisor (cleanup)	Maintenance, general	6.04
51. Boiler operator	Mechanics, auto maintenance	8.75
52. Electrician	Mechanics, auto maintenance	8.75
53. Cooking tower worker	Truckers hauls	5.20
54. Line mechanic	Mechanic, maintenance	10.97
55. Sanitation worker	Cleaner	4.45
56. Janitor	Janitor	4.45
57. Personnel clerk	General clerks	4.24
58. Time keeper	General clerks	4.24
59. Nurse	Secretaries office	6.50
60. Quality control supervisor	Mechanics, maintenance	8.75
61. Lab worker	Stock handler	5.20
62. Oiler/greaser	Auto maintenance	7.83
63. Screening plant worker	General repairs & maintenance	6.04
64. Payroll clerk	Payroll clerk	5.96

Stage VIII. New can stacking

65. Supervisor	Warehouse supervisor	10.41
66. Stocker checker	Stock handler	5.20
67. Palletizer	Stock handler	5.20
68. Hand fork truck operator	Trucker, local haul	6.19
69. Lift truck operator	Truck driver	6.73
70. Transport truck operator	Trucker, local haul	6.19
71. Mechanic	Mechanic, maintenance	10.97
72. Mechanic helper	Trucker's hands	5.20
73. Cleanup worker	Cleaner	4.45

Table XXIV. (continued)

74. Pack accounting clerk	Shipping & receiving clerk	4.29
75. Stretch lab worker	Shipping & receiving clerk	4.29
Stage IX. Cooling floor		
76. Stock checker	Stock handler	5.20
77. Lift truck operator	Truck driver	6.73
Stage X. Pack receiving		
78. Stock checker	Stock handler	5.20
79. Lift truck operator	Truck driver	6.73

[a] Source: Logan (1984).

[b] Source: Center for Economic and Management Research (1988).

APPENDIX B

PROCESSING TOMATO PRODUCTION BUDGET

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PROCESSING TOMATO PRODUCTION BUDGET
DIRECT SEEDED-MACHINE HARVEST FOR SOUTHEASTER OK

    ...........................................................................
    OPERATING INPUTS:                  UNITS      PRICE   QUANTITY       VALUE YOUR VALUE


      VEGETABLE SEED                   LBS.      35.000      1.000       35.00 __________
      NITROGEN (N)                     LBS.       0.170     60.000       10.20 __________
      PHOSPH (P205)                    LBS.       0.150    100.000       15.00 __________
      POTASH (K20)                     LBS.       0.100    100.000       10.00 __________
      HERBICIDE                        ACRE       2.000      1.000        2.00 __________
      HERBICIDE                        ACRE      58.100      1.000       58.10 __________
      FUNGICIDE                        ACRE       2.500      4.000       10.00 __________
      FUNGICIDE                        ACRE       3.400      3.000       10.20 __________
      FUNGICIDE                        ACRE      12.000      1.000       12.00 __________
      INSECTICIDE                      ACRE       5.000      3.000       15.00 __________
      INSECTICIDE                      ACRE       7.700      1.000        7.70 __________
      RIPENER                          GAL.      35.000      0.850       22.75 __________
      HOEING LABOR                     HR.        4.500     15.000       67.50 __________
      CROP INSURANCE                   ACRE      40.000      1.000       40.00 __________
      COVER CROP                       ACRE       8.000      1.000        8.00 __________
      ANNUAL OPERATING CAPITAL         DOL.       0.118     77.089        9.06 __________
      LABOR CHARGES                    HR.        4.500     11.583       52.03 __________
      MACHINERY FUEL,LUBE,REPAIRS      ACRE                              96.83 __________
      IRRIGATION FUEL,LUBE,REPAIRS     ACRE                              35.64 __________

    TOTAL OPERATING COST                                                517.01 __________
    ...........................................................................
    FIXED COSTS                                 VALUE YOUR VALUE


      MACHINERY
        INTEREST AT 11.8%              DOL.    116.303 __________
        DEPR.,TAXES,INSUR.             DOL.    148.703 __________
      IRRIGATION
        INTEREST AT 11.8%              DOL.     17.480 __________
        DEPR.,TAXES,INSUR.             DOL.     19.800 __________
      LAND
        INTEREST AT  0.0%              DOL.      0.000 __________
        TAXES                          DOL.      0.000 __________

    TOTAL FIXED COSTS                          302.27  __________
    ...........................................................................
    PRODUCTION:                        UNITS      PRICE   QUANTITY       VALUE YOUR VALUE


      TOMATOES                         TONS      65.540     15.000      883.10 __________
    ...........................................................................
    RETURNS ABOVE TOTAL OPERATING COSTS                                 466.09 __________

    RETURNS ABOVE ALL COSTS EXCEPT
        OVERHEAD,RISK AND MANAGEMENT                                    163.82 __________
    ...........................................................................
HERB. 1 LEXONE .76 LB AI, 2 ENIDE 6 LB AI                            SCHATZER, HAMID
FUNG 1 COPPER SULFATE 2LBAI, 2 DIATHANE-M45 1.6LBAI, 3 DIFOLATAN          1ST COMP
1.6 LB AI, INS 1 SEVIN 1 LB AI, 2 THIODAN .75 LB AI      07/21/88

      PROCESSED BY DEPT. OF AGRI. ECON. - OKLAHOMA STATE UNIVERSITY
   PROGRAM DEVELOPED BY DEPT. OF AGRI. ECON. OKLAHOMA STATE UNIVERSITY
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BUDGET IDENTIFICATION NUMBER  99 0058801014 1          ANNUAL CAPITAL MONTH  9          BUDGET RECORD NUMBER 328
                                                                                          BUDGET FILE   2

PROCESSING TOMATO PRODUCTION BUDGET
DIRECT SEEDED-MACHINE HARVEST FOR SOUTHEASTERN OK

                        1      2      3      4      5      6      7      8      9     10     11     12      13      14     15   16   17   18
LINE                   JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC    PRICE  WEIGHT  UNIT ITEM TYPE CONT
PRODUCTION                                          NUMBER OF UNITS                                                       CODE CODE
 1 TOMATOES            0.00   0.00   0.00   0.00   0.00   0.00  15.00   0.00   0.00   0.00   0.00   0.00  58.540   0 000   3.   65    2    0

OPERATING INPUTS                                     RATE/UNIT                                           PRICE   NUMBER  UNIT ITEM TYPE CONT
                                                                                                                 UNITS   CODE CODE
11 VEGETABLE SEED      0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  38.000   0 000   12.  199    3    0
12 NITROGEN (N)        0.00   0.00  30.00   0.00   0.00  30.00   0.00   0.00   0.00   0.00   0.00   0.00  -1.000   0 000   12.  211    3    0
13 PHOSPH (P205)       0.00   0.00 100.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  -1.000   0 000   12.  214.   3    0
14 POTASH (K20)        0.00   0.00 100.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  -1.000   0 000   12.  218.   3    0
15 HERBICIDE           0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   2.000   0 000    7   250.   3    0
16 HERBICIDE           0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  95.100   0 000    7   250.   3    0
17 FUNGICIDE           0.00   0.00   0.00   4.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   2.000   0 000    7.  248    3    0
18 FUNGICIDE           0.00   0.00   0.00   3.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   3.400   0 000    7.  248    3    0
19 FUNGICIDE           0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  12.000   0 000    7.  248    3    0
20 INSECTICIDE         0.00   0.00   0.00   3.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   5.000   0 000    7.  240.   3    0
21 INSECTICIDE         0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   7.700   0 000    7.  240    3    0
22 RIPENER             0.00   0.00   0.00   0.00   0.00   0.65   0.00   0.00   0.00   0.00   0.00   0.00  35.000   0 000    5   241    3    0
23 HOEING LABOR        0.00   0.00   0.00   5.00   5.00   5.00   0.00   0.00   0.00   0.00   0.00   0.00  -1.000   0 000    6   328    3    0
24 CROP INSURANCE      0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  40.000   0 000    7.  452    3    0
25 COVER CROP          0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   1.00   0.00   0.00   0.00   5.000   0 000    7   201    3    0

MACHINERY REQUIREMENTS                               TIMES OVER                                          *****   ***** POWER MACH TYPE CONT
                                                                                                                        UNIT CODE
38 CHISEL              1.00   0.00   0.00   0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00   0 000   0 000    3   42    4.   0
39 OFFSET DISK         0.00   2.00   0.00   0.00   0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0 000   0 000    3   37    4    0
40 SPRINGTOOTH         0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   1.00   0.00   0.00   0.00   0 000   0 000    3   53    4    0
41 SPRAYER             0.00   0.00   0.00   4.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.000   0 000    3   74    4    0
42 SU-TB PLANTER       0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.000   0 000    3   64    4.   0
43 TILL CULTIVATOR     0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0 000   0 000    3   47    4    0
44 3P BOOM SPRAYER     0.00   0.00   1.00   1.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.000   0 000    3   75    4    0
45 DRY FERT SPRD       0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.000   0 000    3   71    4    0
46 SIDE PLACE FERT     0.00   0.00   0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00   0.00   0.000   0 000    3   66    4    0
47 DRILL W/O FERT      0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.000   0 000    3   61    4    0
48 TOMATO HARVESTER    0.00   0.00   0.00   0.00   0.00   0.00   1.00   0.00   0.00   0.00   0.00   0.00   0.000   0 000    3   65    4    0


49 ACIN IRRIG WATER    0.00   0.00   2.00   0.00   4.00   6.00   6.00   0.00   0.00   0.00   0.00   0.00

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                                   MONTHLY SUMMARY OF RECEIPTS AND EXPENSES
      CATEGORY          UNIT      JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG      SEP      OCT      NOV      DEC           TOTAL
TOTAL RECEIPTS          ACRE      0.00     0.00     0.00     0.00     0.00     0.00   883.10     0.00     0.00     0.00     0.00     0.00          883.10
TOTAL EXPENSES          ACRE      1.79     7.84   178.85    68.96    30.63    64.07    89.63     3.82    12.14     0.00     0.00     0.00          455.92
RETURNS TO LAND, LABOR, CAPITAL, MACHINERY, OVERHEAD, RISK, AND MANAGEMENT                                                                       427.18
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ANNUAL CAPITAL          DOL.      1.48     2.13    16.88    24.33    38.77     0.00     0.00     0.32     1.33     1.33     1.33     1.33           77.09
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                                   LABOR REQUIREMENTS BY MONTH
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MACHINERY LABOR         HR.       0.19     0.83     1.00     1.11     0.00     0.31     3.52     0.41     0.40     0.00     0.00     0.00            7.77
IRRIGATION LABOR        HR.       0.00     0.00     0.42     0.00     0.84     1.27     1.27     0.00     0.00     0.00     0.00     0.00            3.80
TOTAL LABOR             HR.       0.19     0.83     1.42     1.11     0.84     1.58     4.79     0.41     0.40     0.00     0.00     0.00           11.57
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IRRIGATION WATER        INCH      0.00     0.00     2.00     0.00     4.00     6.00     6.00     0.00     0.00     0.00     0.00     0.00           18.00
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                                   MACHINERY FIXED AND VARIABLE COSTS PER HOUR                          TOTAL
   MACHINE            CODE      DEPR      INSUR.      TAX     TOTAL FIXED   REPAIR       FUEL        LUB.     VARIABLE      INT.       HR/TIME
TRACTOR                 3       5.11      0.28       0.72       6.12        2.58        4.89        0.57       8.04        5.52        1.00
CHISEL                 42       3.21      0.14       0.38       3.74        2.53        0.00        0.00       2.53        2.70        0.18
OFFSET DISK            37       3.81      0.16       0.34       4.31        2.33        0.00        0.00       2.33        3.57        0.24
SPRINGTOOTH            53       1.44      0.07       0.20       1.70        0.80        0.00        0.00       0.80        1.74        0.11
SPRAYER                74       1.61      0.11       0.34       2.05        1.02        0.00        0.00       1.02        2.10        0.13
SU-TB PLANTER          64       3.91      0.17       0.47       4.55        3.56        0.00        0.00       3.56        3.76        0.06
TILL CULTIVATOR        47       2.16      0.08       0.30       2.54        1.72        0.00        0.00       1.72        1.83        0.14
3P BOOM SPRAYER        75       1.90      0.13       0.40       2.43        1.20        0.00        0.00       1.20        2.47        0.24
DRY FERT SPRD          71       4.28      0.28       0.90       5.46        3.38        0.00        0.00       3.38        5.56        0.04
SIDE PLACE FERT        66       1.40      0.05       0.18       1.73        1.35        0.00        0.00       1.35        1.31        0.26
DRILL W/O FERT         61       5.84      0.25       0.71       6.81        5.33        0.00        0.00       5.33        4.81        0.22
TOMATO HARVESTER       65      28.68      1.34       3.81      33.84       11.57        0.00        0.00      11.57       24.71        2.75
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                      ITEM             TIMES  LABOR   MACHINE  FUEL,OIL,LUB.,   FIXED COSTS
  OPERATION           NO.      DATE    OVER   HOURS   HOURS    REPAIR PER ACRE   PER ACRE
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CHISEL               3,42      JUL     1.00   0.190   0.157        1.78             3.02
TOMATO HARVESTER     3,65      JUL     1.00   3.338   2.750       55.18           104.44
OFFSET DISK          3,37      AUG     1.00   0.414   0.242        3.82             7.07
SPRINGTOOTH          3,53      SEP     1.00   0.139   0.111        1.08             1.78
DRILL W/O FERT       3,61      SEP     1.00   0.261   0.218        3.08             5.28
CHISEL               3,42      JAN     1.00   0.190   0.157        1.78             3.02
OFFSET DISK          3,37      FEB     2.00   0.828   0.484        7.64            14.14
SU-TB PLANTER        3,64      MAR     1.00   0.082   0.067        5.78            11.28
3P BOOM SPRAYER      3,75      MAR     1.00   0.302   0.241        2.43             4.27
DRY FERT SPRD        3,71      MAR     1.00   0.047   0.038        0.47             0.83
SPRAYER              3,74      APR     4.00   0.665   0.534        5.39             5.08
TILL CULTIVATOR      3,47      APR     1.00   0.168   0.137        1.48             2.38
3P BOOM SPRAYER      3,75      APR     1.00   0.302   0.241        2.43             4.27
SIDE PLACE FERT      3,66      JUN     1.00   0.313   0.259        2.84             4.07
     TOTAL                                    7.765   6.418       95.83           255.01
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        COLUMN          1       2       3        4       5      6        7        8       9       10      11      12       13      14     15     16     17
NAME OF MACHINE       CODE   WIDTH  INITIAL   SPEED   FIELD   RC1      RC2      RC3    HOURS   YEARS    RFV1    RFV2   PURCHASE  FUEL  HOURS   HP ,   FUEL
                             (FEET)   LIST    (MPH)   EFFIC-                            USED   OWNED                     PRICE   TYPE    OF            MULT
                                      PRICE           ENCY                           ANNUALLY                                         LIFE
TRACTOR                3.    110.0   43500.    4.5    0.85   0.50  0.000831   1.50    500.    10.0   0.880   0.920    43500     3    10000   110   0.048
OFFSET DISK           37.     12.0    7800.    3.9    0.87   0.55  0.000281   1.80    150.    12.0   0.638   0.885     7800     0     2000     0   0.000
CHISEL                42.     15.0    7800.    4.1    0.80   0.55  0.000281   1.80    200.    10.0   0.600   0.885     7800     0     2000     0   0.000
TILL CULTIVATOR       47.     15.0    5300.    5.0    0.80   0.55  0.000281   1.80    200.    10.0   0.600   0.885     5300     0     2000     0   0.000
SPRINGTOOTH           53.     20.0    3000.    5.3    0.70   0.55  0.000281   1.80    150.    12.0   0.600   0.885     3000     0     2000     0   0.000
DRILL W/O FERT        61.     13.3    7100.    6.0    0.72   0.75  0.000831   1.50    100.    10.0   0.600   0.885     7100     0     1000     0   0.000
SU-TB PLANTER         64.      7.5    4750.    3.9    0.67   0.75  0.000831   1.50    100.    10.0   0.500   0.885     4750     0     1000     0   0.000
SIDE PLACE FERT       66.     13.0    1800.    3.6    0.70   0.75  0.000831   1.50    100     10.0   0.500   0.885     1800     0     1000     0   0.000
DRY FERT SPRD         71.     60.0    4500.    5.3    0.67   0.75  0.000831   1.80     50     20.0   0.580   0.885     4500     0     1000     0   0.000
SPRAYER               74.     37.0    1555.    3.5    0.60   0.50  0.002510   1.30     50.    20.0   0.500   0.885     1555     0     1000     0   0.000
3P BOOM SPRAYER       75.     18.0    2000.    3.5    0.60   0.50  0.002010   1.30     50     20.0   0.600   0.885     2000     0     1000     0   0.000
TOMATO HARVESTER      65.      5.0   70300.    1.0    0.60   0.33  0.000301   1.50    300     10.0   0.500   0.885    70300     0     2000     0   0.000
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          HERB. 1 LEXONE .75 LB AI, 2 ENIDE 5 LB AI                         SCHATZER, HAMID      MACHINERY COMPLEMENT   10
          FUNG 1 COPPER SULFATE 3LBAI, 2 DIATHANE-M45 1.5LBAI, 3 DIFOLATAN      1ST COMP         EQUIPMENT COMPLEMENT    1
          1.5 LB AI, INS 1 SEVIN 1 LB AI, 2 THIODAN .75 LB AI     07/31/86                            PRICE VECTOR    4

                  LINE CHANGE            LINE CHANGE            LINE CHANGE            LINE CHANGE            LINE CHANGE
GENERAL NAME CHANGE->201   COVER CROP      65   TOMATOES
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VITA

Abdulhamid A. Elmagsabi

Candidate for the Degree of

Doctor of Philosophy

Thesis: A STOCHASTIC SIMULATION MODEL FOR A TOMATO PROCESSING PLANT IN SOUTHEASTERN OKLAHOMA

Major Field: Agricultural Economics

Biographical:

Personal Data: Born in Benghazi, Libya, June 14, 1954, the son of Abdussalam Elmagsabi and Amina Othman. Married to Naeima Omar on October 22, 1981.

Education: Graduated from Shouhada Yanayer High School, Benghazi, Libya, in 1972; received Bachelor of Science Degree in Agricultural Economics from Alfateh University at Tripoli, Libya in 1977; completed requirements for the Doctor of Philosophy at Oklahoma State University in December, 1988.

Professional Experience: Research Assistant, Department of Agricultural Economics, Oklahoma State University, August 1987 to present. Served as a member of the planning and supervision committee, and marketing department chairman at the Sarir Agricultural Project in Libya, 1977-1979. Teaching Assistant at Garyounis University, Libya, October 1979 to September 1980.