SIMULATION OF STRAWBERRY PRODUCTION IN CALIFORNIA TO EVALUATE SOCIO - ECONOMIC IMPLICATIONS OF ALTERNATE HARVEST SYSTEMS

Thesis for the Degree of Ph. D.

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ABSTRACT

SIMULATION OF STRAWBERRY PRODUCTION IN
CALIFORNIA TO EVALUATE SOCIO-ECONOMIC
IMPLICATIONS OF ALTERNATE HARVEST SYSTEMS

By

Robert Bruce Fridley

The needs of the California Strawberry Industry are analyzed in terms of the possible introduction of improved production and harvesting procedures and equipment which would reduce peak labor requirements and reduce or stabilize production costs. Production trends of the various growing areas are presented and current cultural practices investigated. The essential inputs including labor, materials, and equipment are evaluated. Consideration is given to the labor requirements for strawberries and the effect of these peak labor requirements on the total labor needs in the production areas. Social consequences of mechanization including 1) the general effects of mechanization on labor and 2) the problems of short duration jobs and migration of farm labor are discussed. The state of current strawberry harvest research is reviewed. Criteria for evaluation of alternatives are established.

Several alternatives are synthesized for mechanization of harvest or improvement of harvest techniques. Emphasis is placed upon the harvest operation since the peak labor force and a relatively large portion of the costs are associated with harvest. A feasibility analysis of proposed solutions is made to evaluate realizability and practicability. Based upon

the feasibility study, once over machine harvest and selective harvest by machine are judged to be unfeasible. The set of feasible solutions includes 1) supplementing hand picking during the peak season with some form of multiple pick, semi-selective, machine harvest, 2) supplementing conventional hand picking during peak season with harvest of selected fruiting stalks (cymes) that have several berries most of which are mature, and 3) use of a totally new production system whereby plants are grown on a vertical bed -- called a strawberry wall.

A macroscopic simulation model was developed to evaluate the set of feasible solutions under a stochastic production situation. A building block approach was used for the model which simulated production timing and quantity as random variables. A harvest algorithm was developed to simulate the picking operation.

Results are presented which indicate that supplementing hand harvest with machine harvest is not likely to maintain grower income, primarily due to expected loss of fruit. The solution of picking some fruits by harvesting cymes shows good potential, provided that pickers can achieve a substantial increase in net picking rate without an excessive loss of fruits. The strawberry wall shows good potential from a grower point of view, but would cause a large reduction in total labor requirements. In addition, assumptions used to evaluate the strawberry wall are quite subjective and as a result, further tests are necessary before final evaluation can be made.

The simulation study indicates that it is possible to consider proposed automated systems as socio-economic systems and develop information about the change of worker needs and possible displacement. Results can aid engineers in making technical decisions and aid social scientists in anticipating the possible displacement of labor.

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1. INTRODUCTION

Production of strawberries in the United States has declined rather steadily over the past 15 years. The 1957 production was nearly 555 million pounds, and it declined to 511 million pounds in 1963, 486 million pounds in 1969, and 474 million pounds in 1970 (Antle, 1970). This trend is primarily caused by, 1) increased import of strawberries, 2) greater competition from crops which have benefited from technological advances including mechanization, 3) high production cost, and 4) high labor requirements.

California leads all other states in strawberry production. In 1970, California accounted for 55 percent of the U.S. production on 7 percent of the U.S. acreage (Antle, 1970). Yields in California are relatively high, but even so, California strawberry acreage has declined along with that of other states. High production costs, high land value, and high shipping costs offset the advantage of high yields.

In recent years there has been an increasing concern about the future of the California strawberry industry. Imports of both fresh and frozen strawberries from Mexico have made substantial inroads into the U.S. market. Also, an inadequate supply of labor during peak harvest has caused some growers to reduce acreage. Although technology has provided growers with increased yields which have balanced increased production costs, this does not seem to provide a continuing solution. In addition, states which primarily produce frozen berries may soon be able to mechanize harvest, thus accomplishing a competitive gain over California.

The future of the strawberry industry in California is not only important to the growers of strawberries and the consumers who like berries, it is also important to several thousand workers who plant, harvest, and otherwise aid in producing and marketing. Even with the current situation many workers, particularly field workers, have a substandard annual salary, a factor which contributes to the labor shortage noted by growers. The low annual salary may be attributed in part to a relatively low wage rate; but more importantly annual salary is limited by the short working period associated with harvest during production peaks.

Hopefully, an improved production and harvest system could brighten the economic future of the strawberry industry and further could provide better, more stable, and higher income employment for workers. Improved systems might be brought about by any one of several innovations. However, substantial research time and money will no doubt be required to develop an effective system. Further, there are undoubtably many possible solutions which, if developed, would be relatively ineffective or impractical. The subject of this thesis is to predict system concepts which seem to have substantial potential and identify those which are not likely to be practical. With some crops predictive analysis could have identified systems which failed to be practical once they were developed (Fridley and Adrian, 1968, and Stout and Kline, 1968). Examples of these systems are selective harvesters for cucumbers, asparagus, and lettuce (Harriott, et al. 1969, Kepner, 1971, Knicely, et al., 1963, Stout, 1969, and Stout, et al., 1963). Obviously predictions are limited by the validity of the assumptions made and the accuracy of the data used.

2. OBJECTIVES

It is the purpose of this thesis to analyze the needs of the California Strawberry Industry in terms of possible changes in production and harvesting procedures and equipment, to consider the feasibility of potential changes, and to evaluate the merits of changes found to be most feasible. Further, it is hoped that the results of this thesis will provide needed direction to the research and development of improved harvest systems which will benefit the growers, the consumers, and the workers alike. This study is specifically intended to consider the strawberry industry as a socio-technological system and to evaluate both the social and economic implications of any potential changes.

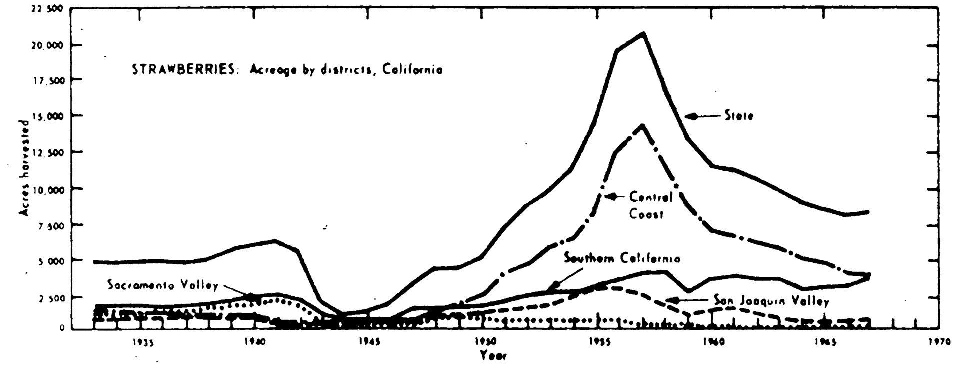
3. THE STATE OF THE INDUSTRY

Strawberry production in California is a 50 million dollar a year industry which is primarily located in Southern California (Orange, Los Angeles, Ventura, San Diego and Riverside Counties), the Central Coast (Santa Clara, San Benito, Alameda, Monterey, Santa Cruz, San Luis Obispo, and Santa Barbara Counties), and the Central Valley (San Joaquin, Stanislaus, and Fresno Counties). After World War II acreage in California increased and reached a peak of 20,700 in 1957. Subsequently, acreage has decreased to approximately 8,000 acres with Southern California being the only area that is relatively unchanged (Johnston and Dean, 1969). They reported that initial decline in acreage was an adjustment of supply and demand of frozen berries. As the acreage decreased, changes in varieties and cultural practices caused substantial increases in yield. The net effect was a highly variable, but generally unchanged, total production (Figure 1).

In the 1960's, the production of fresh market fruit increased and is now nearly three-fourths of the total production. The long harvest season (Figure 2) was initially important in developing the frozen berry market and has continued to be important in producing fresh market berries. The long season provides a supply of fruit from early spring to late fall and also increases yield potential.

Both the fresh and frozen markets are important to California producers. The fresh market is the primary one but the frozen market provides an important outlet for small berries and berries produced when fresh market prices are low.

Size of farms which produce strawberries has increased over the past several years. About 55 percent of the farms account for 90 percent



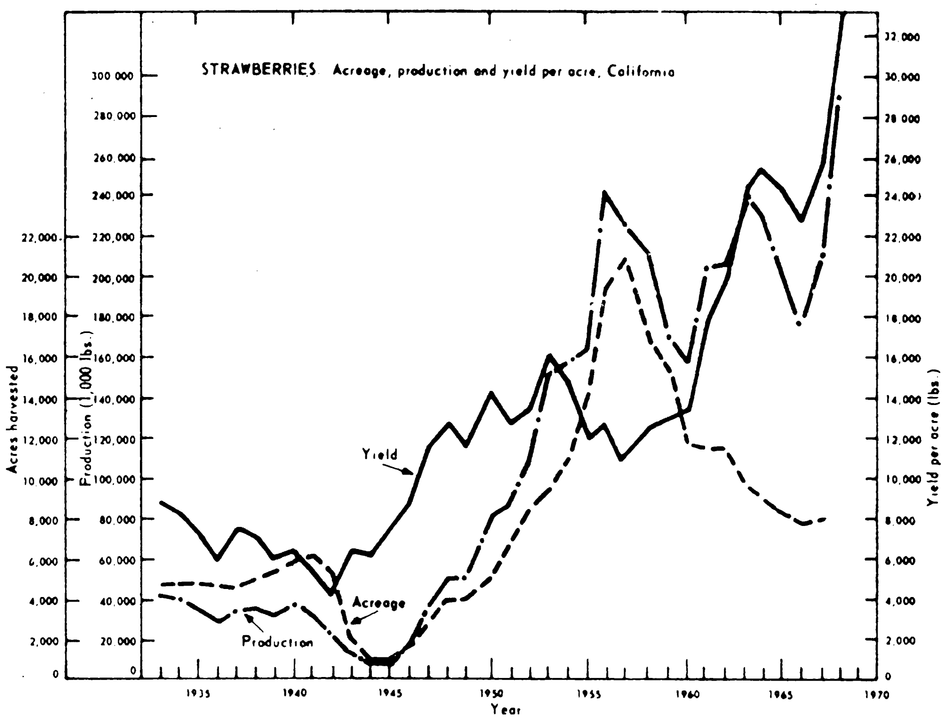


Figure 1 Strawberry Production Trends in California (Johnston and Dean, 1969)

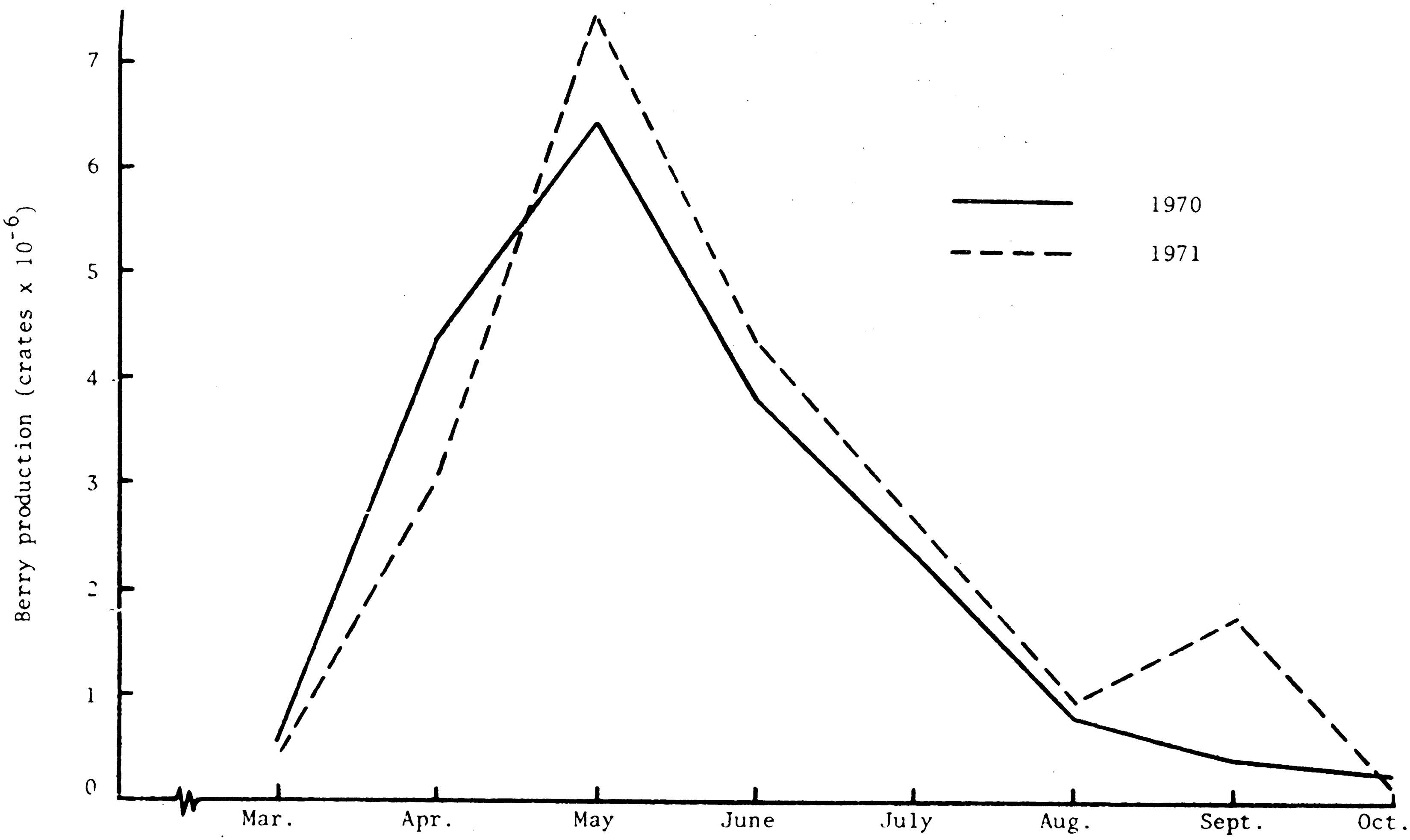


Figure 2 Total Production of Strawberries in California by Month
(Data Courtesy of Processing Strawberry Advisory Board of California.)

of the acreage and these farms range from about 5 acres to several hundred acres. The balance are small farms which frequently produce low yields in the order of 50 percent of the yields produced on the larger farms.

3.1 Production trends of various districts

Southern California produces the first berries in the state. Harvest begins sometime in late February or early March, reaches a peak production about a month later, and yields berries on into the summer. This area produces about 125 million pounds of berries, 78 percent for the fresh market and 22 percent for freezing. Much of the freezer fruit comes from late season harvest. Approximately 3,700 acres in Southern California produce an average yield of nearly 18 tons per acre. (For comparison, four leading states, Florida, Michigan, Oregon, and Washington produce about 4.5, 2.5, 3.4, and 3.2 tons per acre, respectively).

The Central Coast production lags that from the southern part of the state. One production peak occurs in May with a second smaller peak about August or early September (Bain and Hoos, 1963). Berries are available for marketing from late April until mid-November. Production is about 115 million pounds of berries per year produced on about 3,500 acres. Approximately equal amounts of fruit go to the fresh market and the frozen fruit market. Most fruits used for freezing are harvested from second year or older plants which tend to bear small fruits.

About 60 million pounds of berries are grown in the Central Valley, all for fresh market. The harvest season of 2 months in this district is the shortest in California. Peak production leads the Central Coast by about 2 weeks, but warm spring temperatures force a short season. Weekly production for Southern California and the Central Coast are given in Figures 3 and 4, respectively, for 1968 thru 1971.

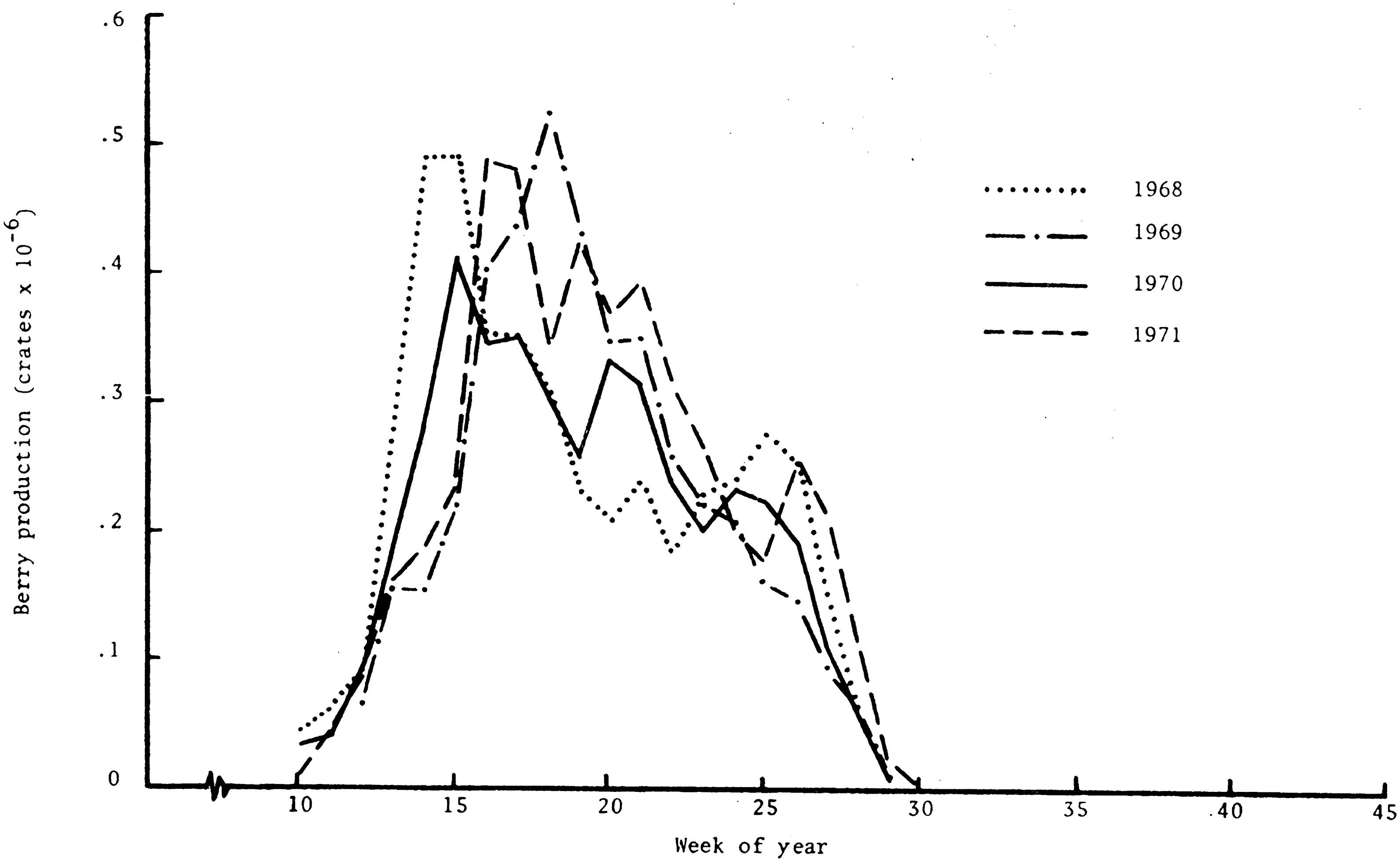


Figure 3 Weekly Production of Strawberries in Southern California
(Data Courtesy of Processing Strawberry Advisory Board of California.)

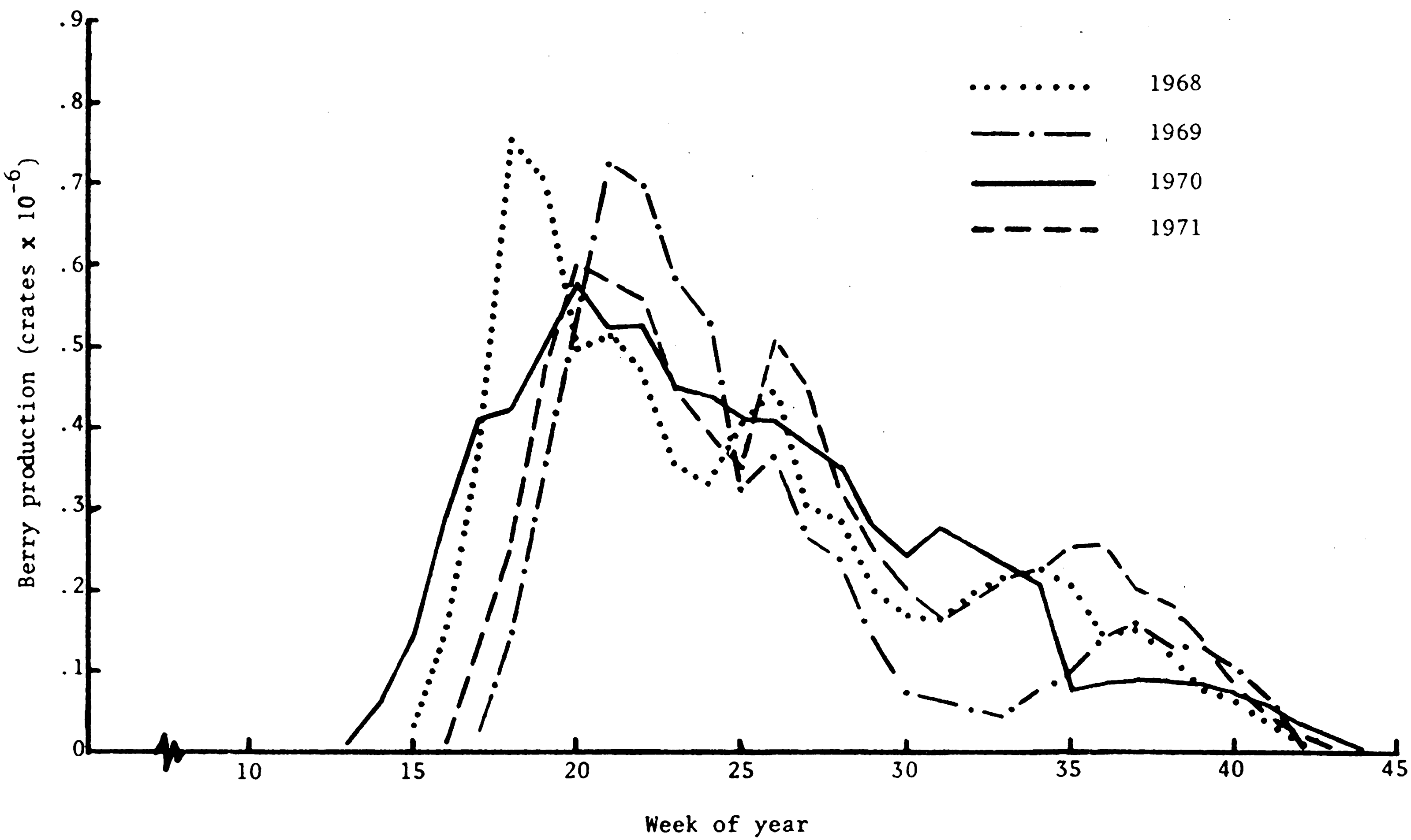


Figure 4 Weekly Production of Strawberries Along the Central Coast (Data Courtesy of Processing Strawberry Advisory Board of California.)

3.2 Current production practices and cultural operations

Strawberry production in California can be classified both by the geographical areas and by planting practice -- summer planting or winter planting (Waldo, et al., 1968, Greathead, et al., 1968, and Holland, et al., 1967). Summer plantings are very popular since they produce high yields, nearly twice the yields of winter plantings, and they are adaptable to all three production areas. Winter plantings in Southern California are primarily for an early fruit crop; the early season typical for the area together with early production induced by winter plantings permits growers to market fruit when prices are high. A second peak on winter plantings usually occurs between two peaks of the summer plantings.

Summer planting consists of planting young plants which have been held in cold storage. Following transplanting the plants are carefully irrigated and fertilized and during the fall any blooms or runners are removed to promote vegetative growth. During January or February plants are lightly pruned by removing some large outer leaves, fertilized, and a polyethylene mulch is applied over the bed surface. The polyethylene used is usually clear although black is sometimes used for weed control. Clear mulch induces higher soil temperatures which in turn accelerate plant growth and fruit development in the spring (Waldo, et al., 1968).

Winter planting is done in November or December. The transplants are grown at high elevation nurseries and are kept for little or no time in cold storage. Winter chilling of the plants occurs before the transplants are moved so the plants can produce a good first year crop when planted in relatively mild coastal or southern California areas. Winter temperatures of the Central Valley are not mild enough for dependable active growth following planting which is essential to produce an early high yield. Following winter planting polyethylene mulch is applied soon after planting. In the Central Coast area where winter plantings are kept for more than one year, the mulch is removed following the first years harvest so sprinkling and winter rains can leach accumulated salts (Greathead, et al., 1968).

About 60 percent of the Southern California acreage is summer planted and 40 percent winter planted. Crops are planted annually with summer and winter plantings often being alternated where berries are not rotated with other crops. Alternating summer and winter plantings provides for two crop years every three calendar years. Both summer and winter plantings are kept for one crop year (Holland, et al., 1967).

The Central Valley area uses only summer plantings and the short season permits one planting and harvest cycle each year.

The Central Coast is making a transition from winter planting to summer plantings. The harvest season extends beyond the time for summer planting, so growers who summer plant get one crop every other year or two crops every three years. Winter plantings eliminate the nonproductive year but have low yields. Disadvantages of multiple crop years are low yields and poor fruit size, and quality (Greathead, et al., 1968).

Planting Dates The two planting periods, summer and winter, used in California are important for extending the harvest season and thereby increasing sales potential. Planting dates are given in Tables 1 and 2. In personal correspondence, Dr. Royce Bringhurst, Chairman, Department of Pomology, University of California, Davis, indicated that the time of planting is very important -- for example, yield of Tioga variety may be reduced by as much as 20 percent by planting 15 days after the optimum. Waldo et al., 1968, state that planting two weeks early or two weeks

Table 1 Recommended Planting Dates for Central Coast and Central Valley (Greathead, et al., 1968)

Variety	Recommended Planting Dates: Central Coast	Central Valley
	Summer Plantings	
Tioga	July 20 to Aug 1	July 5 to July 15
Fresno	July 25 to Aug 1	July 10 to July 20
Shasta	Aug 1 to Aug 10	
Salinas	Aug 5 to Aug 15	July 15 to July 25
	Winter Plantings	
Tioga	Nov 1 to Nov 5	
Shasta	Nov 15 to Nov 20	
Aliso	Nov 15 to Nov 25	

Table 2 Recommended Planting Dates for Southern California (Holland et al., 1967)

Variety	Recommended Planting Dates
	Summer Plantings[1]
Tioga	July 25 to Aug 10
Solano	Aug 1 to Aug 10
Fresno	Aug 5 to Aug 20
Torrey	Aug 20 to Sept 10
Aliso & Salinas	Aug 25 to Sept 10
	Winter Plantings
Tioga	Nov 1 to Nov 5
Fresno	Nov 10 to Nov 20
Lassen	Nov 20 to Nov 30
Aliso	Nov 20 to Nov 25

[1] Dates for summer planting in San Diego County are about 10 to 20 days later than other Southern areas.

late can make a crucial difference. Data on the effect of planting date on yield are given in Table 3, which also presents information on harvest date and relation to planting date for Southern California.

In California the most common procedure is to plant a double row on a raised bed. This type of planting generally gives best yield on summer plantings. Winter plantings are usually planted in a single row which exposes the surrounding ground to the sun, increasing soil temperature and hastening ripening. Several growers in the Central Coast have informed the author that they are changing over to single rows for summer plantings in order to make berries more visible to pickers.

Cultural Operations In addition to planting, the shaping of beds, irrigation, fertilization, soil fumigation and bed mulching are very important. Bed shaping and irrigation practices must minimize salt build up near the crown of the plants (Waldo, et al., 1968). The soil must be well irrigated to keep the necessary supply of water available to the plants. One procedure for leaching salts from the soil is to use sprinkler irrigation on young plantings. Dr. Bringhurst told the author that a second procedure is to run a small furrow down the top of the bed between the double rows so the water is applied as near as possible to the crown and thus tends to leach salts down through the soil.

A new irrigation method and bed shape has been reported (*American Fruit Grower*, May, 1972). Trickle irrigation in the root zone was reported to reduce water consumption by one-third. A more significant finding was a yield increase of about 70 percent accomplished in part by using a high plant density. A conventional 40-inch bed had 62,725 plants per acre and 60-inch bed had 83,630 plants per acre. Another advantage of the wider bed was reported to be that water can be applied near the plants which reduces salt buildup and promotes more vigorous plants.

Table 3 Effect of Planting Date on Total and Monthly Yield of Winter Planted Strawberries (Voth and Bringhurst, 1970).

Planting Date	Average Fruit Size	Yield					
		Feb	Mar	April	May	June	Total
	(gms/fruit)	(grams per plant)					
	Tioga Variety						
Oct 15	12	70	130	60	110	180	550
Nov 1	14	40	130	140	210	160	680
Nov 15	15	0	120	130	270	120	640
Dec 1	13	0	80	40	20	0	140
	Lassen Variety (Aliso variety similar)						
Oct 15	11 (13)1/	40	140	40	110	180	520
Nov 1	11 (14)	40	140	80	110	230	600
Nov 15	12 (17)	10	120	140	230	200	700
Dec 1	13 (18)	0	120	60	320	160	660
Dec 15	12 (14)	0	50	50	20	0	120
	Shasta Variety						
Oct 15	9	30	50	20	50	80	230
Nov 1	11	20	80	50	90	110	350
Nov 15	13	0	90	80	110	170	450
Dec 1	16	0	80	70	150	40	340
Dec 15	13	0	40	40	40	0	120
	Fresno Variety						
Oct 15	10	50	80	40	50	100	320
Nov 1	11	20	80	50	80	140	370
Nov 15	14	0	90	110	180	180	560
Dec 1	13	0	80	20	110	120	230
Dec 15	11	0	40	20	0	0	60

1/ Numbers in parenthesis are for Aliso variety.

Application of fertilizer can be very beneficial. Voth and Bringhurst, 1968, report that an application of 100 to 200 pounds per acre of ammonium sulfate nearly doubled fruit yield. However, in personal correspondence, Dr. Bringhurst cautioned that excess nitrogen may cause significant softening of the fruit and also may cause excessive vegetative growth that makes harvest more difficult and expensive.

As discussed previously, clear polyethylene is generally used as a mulch and soils are fumigated for control of weeds and disease.

Relative importance of varieties The importance of different varieties is illustrated by the data given in Tables 4 and 5. Table 4 indicates that three varieties provide most of the acreage. Table 5 shows that Tioga is increasing in popularity for freezer pack and a new variety, Aliso, is just coming into production. High yield, firm texture, and good appearance make Tioga the leading variety. In personal correspondence, Dr. Bringhurst indicated that if the Tioga rather than Shasta variety was used in the Central Coast region, yield per acre would be 33 to 50 percent higher and the longer firmer fruit of Tioga variety is more adapted to mechanized handling than are Shasta fruits.

A new variety, Tufts, recently released for California conditions shows promise, particularly for summer planting. Bringhurst has said that it has out yielded Tioga and has good quality and a long-conic shape which changes less than does Tioga as the season progresses. Fruit is firm and well adapted to mechanized handling.

3.3 Essential inputs for current production system

Inputs required for the several cultural operations and harvest are itemized in Tables 6 and 7 along with associated costs. The two operations which are generally considered to require considerable labor are

Table 4 Total Acreage of Strawberries in California in 1970 by Variety (Data Courtesy of Processing Strawberry Advisory Board of California).

Variety	Acreage: First Year: Summer planted	Acreage: First Year: Winter planted	Acreage: Second year and older	Per cent of total acreage
Tioga	1,520	1,100	370	35.2
Shasta	840	40	1,200	24.5
Fresno	1,420	140	60	19.0
Other	440	830	540	21.3

Table 5 Total Freezer Pack by Variety (Data Courtesy of Processing Strawberry Advisory Board of California).

Variety	Freezer pack by year: 1970	1969	1968	1967
	(per cent of total pack)			
Shasta	35	33	34	35
Tioga	38	28	16	7
Fresno	23	25	36	27
Torrey	--	6	3	10
Lassen	--	2	4	5
Aliso	--	1	0	0
Others	4	5	7	16

transplanting and harvest. More man-hours are required for irrigation, weeding and cutting runners, and laying plastic mulch than are required for transplanting, but the importance of timing make transplanting more critical. Harvest takes more labor than all other operations combined.

Transplanting is basically a hand operation although some growers use machine aids that have a disk set to open a narrow trench to accommodate the roots. A few machines are designed to carry laborers who set plants in place and press dirt firmly around the roots.

Harvest is all done by hand. Pickers go thru the fields every 4 or 5 days and pick fruits that have reached the proper degree of ripeness. Pickers place fruit directly into a tray or crate which holds about 12 pounds. The fresh market tray contains 12 baskets and is prepared in the field by the picker for shipment.

Cost of production varies from area to area depending upon frequency of planting, number of plants per acre, mulching practices used, etc. Costs listed in Tables 6 and 7 are typical of those reported for several counties. Most costs vary in proportion to the acreage involved; however, harvest is usually done on a piece rate basis so harvest cost is in proportion to yield.

Cost of planting is, of course, largely determined by the number of plants per acre. Summer plantings would typically have about 25,000 plants per acre set in double rows on a 40-inch bed; winter plantings about 11,000 plants per acre set in single rows on a 36-inch bed.

The per acre cost is, of course, affected by farm size. The average size is reported to be increasing with time. Johnston and Dean, 1969, report a trend towards more 100 to 200 acre farms. A relatively small number of relatively large farms tend to raise the average above

Table 6 Typical Inputs and Costs Required for the Production of Strawberries. (Data from Several California County Cost Records Which Were Updated to Reflect Current Prices).

Operation	Inputs Per Acre	Charge[1/] Rate	Total Cost Per Acre
		(dollars/unit)	(dollars)
	Cash Costs for Cultural Operations		
Field preparation	Skilled labor - 20 hrs.	$3.00/hr	$60.00
	Equipment - 20 hrs.	1.20/hr	24.00
Soil Fumigation	Skilled labor - 7.5 hrs.	3.00/hr	22.50
	Equipment - 7.5 hrs.	1.20/hr	9.00
	Fumigant & Plastic		320.00
Bed Preparation and Planting	Skilled labor - 2 hrs.	3.00/hr	6.00
	Common labor - 45 hrs.	2.20/hr	99.00
	Equipment - 2 hrs.	1.20/hr	2.40
	Plants - 30K/acre	20/K	600.00
Irrigation	Common labor - 70 hrs.	2.20/hr	154.00
	Equipment - 35 hrs.	1.20/hr	42.00
	Water - 67 in.	18/ac-ft	100.00
Cut Runner & Weed	Common labor - 80 hrs.	2.20/hr	176.00
Pest Control	Skilled labor - 4 hrs.	3.00/hr	12.00
	Equipment - 4 hrs.	1.20/hr	5.00
	Pesticide		100.00
Fertilize	Skilled labor - 2 hrs.	3.00/hr	6.00
	Equipment - 2 hrs.	1.20/hr	2.50
	Fertilizer		172.00
Prune Old Leaves	Common labor - 50 hrs.	2.20/hr	110.00
Plastic Mulch	Skilled labor - 2 hrs.	3.00/hr	6.00
	Common labor - 75 hrs.	2.20/hr	165.00
	Equipment - 2 hrs.	1.20/hr	2.50
	Plastic		84.00
		TOTAL	2270.00
	Fixed Costs and Overhead		
Total operation (includes equipment and land)			
Depreciation			136.00
Interest			41.00
Taxes on equipment			6.00
Rent			150.00
		TOTAL	333.00
		GRANDTOTAL	2603.00

1/ Includes compensation insurance and Social Security.

the median. Many small farms still exist.

Holland et al., 1967, indicate a total cash cost per acre of $1,897 in 1965 for Orange and San Diego Counties in California excluding harvest costs. This figure includes $528 for labor. Cost of harvest in 1971 was indicated as $.80 to $1.25 per crate (12 pounds net) plus 30 cents for the crate and 10 cents a crate for handling. Yields of 2,500 to 4,500 crates per acre from summer planted berries, and 1,500 to 3,000 trays from winter planted berries give a harvest cost of about $2,200 to $7,200.

Table 7. Typical Inputs and Costs for Harvest of Strawberries (Data from Several California County Cost Records)

Inputs	Charge Rate	Cost Per Acre[2/]
	(dollars/unit)	(dollars)
Picking	.90/crate[1/]	$3,150.00
Checker - 54 hrs/acre	2.20/hr	116.00
Hauling labor - 20 hrs/acre	3.00/hr	60.00
Hauling equipment - 20 hrs/acre	2.00/hr	40.00
Crates and Baskets	.35/crate	910.00
Cash Overhead		200.00
		$4,476.00

[1/] Rate given is for picking berries for fresh market. Additional time required for removing caps and stems on freezer berries increases rate to about $1.20 per 12 lb crate.

[2/] Assuming yield of 3,500 crates or 21 ton per acre.

3.4 The labor picture in the two major production areas.

Strawberries represent a major user of seasonal labor in the Central Coast area and in Southern California. Thus, the overall farm labor situation is of particular interest in these two production areas.

Table 8 gives the total number of seasonal workers and the number of seasonal workers employed in strawberries in Central Coast Counties (Monterey, Santa Cruz, Santa Clara, and Alameda) and in South Coast Counties (San Diego, Orange, Los Angeles, Ventura, Santa Barbara and San Luis Obispo). From the data, it is evident that a significant part of the peak in total seasonal workers employed in agriculture is due to the peak labor requirements of strawberries. The peak for strawberries is primarily associated with harvest; however, along the Central Coast, summer planting during July adds to the peak employment. Growers generally don't consider planting as a labor problem, though, because planting occurs during a time of reduced labor requirement for harvest and planting tends to keep laborers from leaving. Along the Southern Coast summer planting contributes little to the peak, requiring labor from late July into September which is well after the employment peak caused by harvest.

Labor is very critical to the strawberry industry. A picker can average about 2 to 3 trays per hour throughout the season so the labor required just for harvest is about 1000 to 2000 man-hours per acre. An additional 50 to 100 man-hours per acre is required for harvest related activities and about 200 to 400 man-hours for cultural operations. Pickers spend about 83.3 percent of the time picking, 8.5 percent moving and changing rows, 6.6 percent carrying and changing trays, and 1.6 percent on personal activity (MacGillivray and Stevens, 1964).

Certainly since termination in 1964 of Public Law 78, which made workers available from Mexico, uncertainty about, and some shortage of, labor has had an effect on the strawberry industry. Snyder and Osgood, 1965, in discussing the outlook for strawberries in Santa Barbara and

Table 8 Employment[1/] of Seasonal Workers[2/] in Agriculture and in Strawberries (Data Courtesy of the Rural Manpower Services, California Department of Human Resources Development).

Year and Month	Seasonal Workers			
	South Coast[3/]		Central Coast[4/]	
	Total	Strawberries	Total	Strawberries
1971				
January	8,130	75	2,920	40
February	11,030	240	2,890	140
March	13,000	1,200	4,060	160
April	18,610	4,380	6,630	540
May	22,720	6,750	11,560	2,700
June	21,900	5,500	12,840	2,720
July	18,930	2,590	17,310	1,950
August	18,960	900	14,540	1,450
September	18,860	470	17,450	810
October	17,100	380	9,090	60
November	14,030	420	6,140	30
December	12,480	230	3,130	30
1970				
January	7,370	110	2,080	50
February	9,620	250	4,390	190
March	13,940	1,330	5,000	250
April	20,570	4,490	9,470	1,640
May	21,670	6,510	12,230	3,140
June	21,850	5,640	14,230	3,150
July	18,930	2,610	17,600	2,210
August	18,460	830	17,330	1,380
September	19,580	510	14,270	540
October	15,710	450	10,220	240
November	11,110	360	5,740	120
December	8,760	200	4,930	90

1/ Estimated man-weeks of labor required.

2/ Employed less than 150 days.

3/ Includes San Diego, Orange, Los Angeles, Ventura, Santa Barbara, San Luis Obispo and San Bernardino Counties.

4/ Includes Monterey, Santa Cruz, Santa Clara, and Alameda Counties.

San Luis Obispo Counties, stated that "Because of the uncertainty of labor supply, some reduction in the 1965 acreage is anticipated". Although acreage in all of California saw a reduction that year, 25 million pounds of strawberries were not marketed due to harvest difficulties (Johnston and Dean, 1969). The Central Coast acreage declined about 10 percent from 1970 to 1971 due to concern about insufficient labor during the peak harvest season, and the Crop and Livestock Reporting Service projected another 10 percent decrease, in 1972.

Costs associated with labor are also important to California strawberry growers. In 1967, the average farm wage rate of $1.59 in California was 47 percent more than the U.S. average farm labor wage rate (Thor and Mamer, 1969). Data presented earlier in Tables 6 and 7 reflect wage rates common in the California strawberry industry in 1971.

3.5 Social consequences of mechanization

A discussion of possible mechanization and the associated labor picture would not be complete without some discussion of the effects of mechanization on farm laborers. In Section 1.0, it was stated that a major reason for the substandard annual wage of many farm laborers is the short period of time during which work is available. Further, the preceeding section points out that strawberry harvest involves many short duration jobs which occur simultaneously with the peak in total season employment in agriculture. In other words, strawberry harvest is a major cause of short duration jobs. Employment figures (Lenhart, 1967) indicate that about 20 percent of the workers employed in strawberry production (about 12,000 workers) worked for a period of less than 2 months and 1 1/2 months in 1966 and 1967, respectively. Since these workers are employed during the period of peak employment, many cannot readily find additional employment and a work period of about two months does not provide a reasonable annual wage.

Many authors have discussed the laborers situation and the implication of mechanization, but they fail to agree on desirable solutions. Curley and Thor, 1964, stated that "Mechanization seems to be the only real solution for both agriculture and the worker....It will enable the workers who remain in agriculture to have more days of employment, to obtain higher wages, and to have greater annual incomes". They also caution that mechanization of some operations does not lessen peak employment needs and that mechanization of one crop or operation may have an adverse effect on others. A migrant worker who has a crop employment pattern may have his job sequence altered by mechanization. They point out that "From a worker's standpoint, one of the most important problems is earning a sufficient annual income to provide for his family and himself".

The effects that engineering progress may have on agricultural workers were discussed by Lewis and Williams, 1970. They state "advantages of mechanization have been primarily in favor of the grower. The farm worker has realized some limited advantages, namely, that his work load is lightened when he can work on a machine rather than doing the operation manually". The fact that many workers have a work period which is too short for earning a reasonable annual wage is recognized, but it is pointed out that mechanization is frequently used for operations which do not occur during peak labor periods. Lewis and Williams suggest use of a closed system approach in which economic needs of any persons displaced from jobs by automation are transferred within the system.

Many sociologists have viewed the problems of farm workers. An unpublished review by Isao Fujimoto, Department of Behavioral Sciences, University of California, Davis, was entitled "Mechanization and Farm Labor: Inequities and Social Consequences". Fujimoto concluded that although productivity, efficiency, and growth are measures of technological advancement, such realities as rural poverty, ethnic isolation, and a corporation system of agriculture can be negative results. Fujimoto states "The impact of mechanization on agriculture and the farm labor market must take into account more than labor economics. It also involves the politics of labor, population migration across borders, the exodus from rural slums to urban ghettos, and new forms of social organization". In addition to technological revolution, many factors are considered to have an adverse effect on farm workers. Examples are ineffective labor management practices, poor working conditions frequently brought about by poor field management, poor housing, ineffective or uninformed laws and regulations, and "institutional barriers".

The effective organization and management of agricultural labor was studied in some detail by MacGillivray and Stevens, 1964. They suggest four methods to increase worker output, 1) human relations, 2) rearranging the work pattern, 3) labor aid equipment, and 4) labor replacement equipment. As listed, these methods are in the order of desirability considering social aspects. MacGillivray and Stevens also give the characteristics of a good place to work as determined by a survey of agricultural workers in Fresno County, California (Table 9). It is clearly evident that in the opinion of workers, pay is the most important characteristic. In addition to pay, the characteristics of kind of work, work period, and use of incentive pay might be altered by use of a new

Table 9 Characteristics of a Good Place to Work - Worker's Opinions[1/] (From MacGillivray and Stevens, 1964).

Single Worker

Local		Migrant	
Pay	2.3	Pay	2.0
Kind of work	4.7	Housing	2.8
Length of work day	5.8	Food	4.2
Fairness	5.9	Length of work day	5.5
Foreman's interest	6.2	Fairness	6.3
Travel distance	6.5	Foreman's interest	6.4
Work period - weeks	6.9	Work period - weeks	7.1
Housing	7.3	Kind of work	7.4
Incentive pay	7.3	Foreman's directions	7.9
Foreman's directions	7.3	Incentive pay	8.4
Food	7.5	Travel distance	8.7
Spare time	10.2	Spare time	10.7

Family Man or Man and Family

Local		Migrant	
Pay	2.1	Pay	1.9
Housing	5.3	Housing	3.7
Length of work day	5.8	Length of work day	5.0
Fairness	5.8	Fairness	6.0
Kind of work	5.8	Foreman's interest	6.4
Work period - weeks	6.2	Work period - weeks	6.4
Food	6.6	Kind of work	6.6
Foreman's interest	6.7	Incentive pay	7.2
Travel distance	7.3	Foreman's directions	7.5
Foreman's directions	7.6	Travel distance	8.0
Incentive pay	7.8	Food	8.7
Spare time	10.9	Spare time	10.5

[1/] Arranged in order of importance with preference rating.

production system. Although work period is considered much less important than pay, this could reflect the transient nature of many agricultural workers. They can be quite concerned about the total amount of work they get in a year, but not as concerned about the work period for any one job. The aspect of incentive pay is particularly important in relation to possible use of labor aids, some of which make incentive pay difficult if not impossible. The interrelationship of incentive pay, yield, and work output is illustrated in Figure 5.

3.6 The marketing situation

As stated at the beginning of Section 3.0, 1957 was a year of peak production after which acreage declined as production of frozen fruits stabilized. Production trends of strawberries and other frozen fruits are illustrated in Table 10. It is noted that strawberries represent the largest production of frozen fruits, but production for 1965-67 was 17 percent less than for 1955-57. A major factor in this trend is competition from other crops, including some which have been mechanized during the past 10 or 20 years. This fact was documented by Crosby, 1969 and can be seen in Table 10 by observing the change for strawberries compared to other crops, particularly blueberries.

The per capita consumption of fresh and frozen strawberries is given in Table 11. It appears that there is a gradual decline in consumption of fresh berries. The peak production in 1957 is reflected in the high consumption of frozen berries which dropped off rather markedly by 1959-61. The data indicate that the reduction in strawberry production from 1955-57 to 1959-61 was largely due to a decrease in per capita consumption of frozen berries, probably caused by the competition documented by Crosby, 1969. However, the reduction from 1959-61 to 1965-67 was due

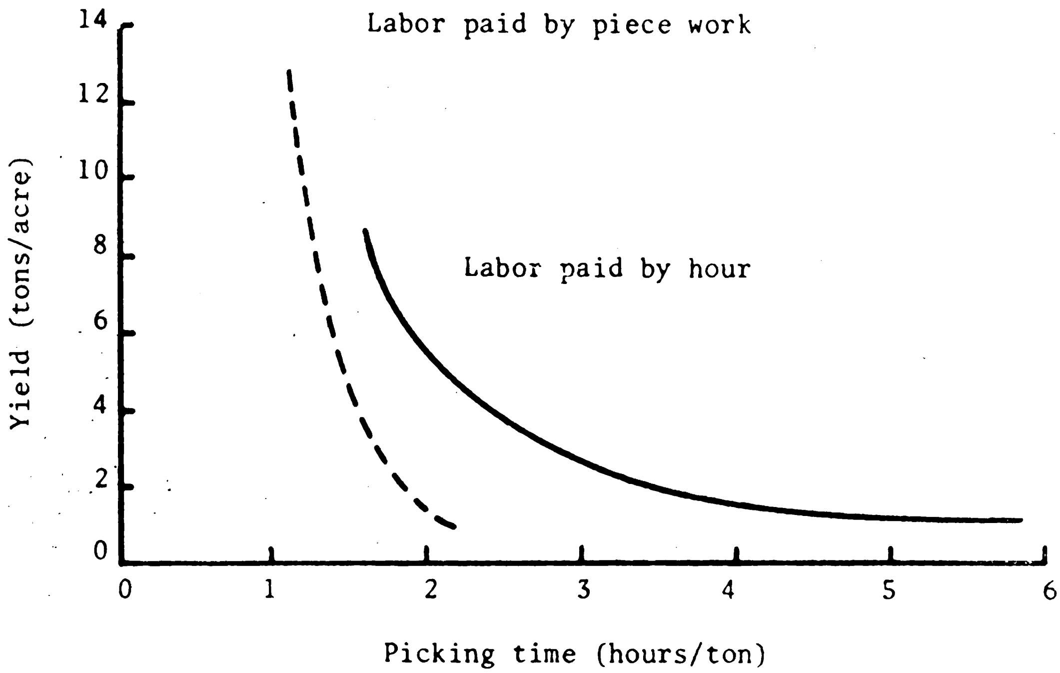


Figure 5 Relationship of Yield and Picking Time For Harvesting Honeydew Melons (MacGillivray and Stevens, 1964)

Table 10 United States Production of Frozen Fruits (Crosby, 1969)

Crop	U. S. Production 1945-47	1955-57	1965-67
	(thousands of pounds)		
Apples	57,327	76,313	95,126
Apricots	38,245	8,380	19,297
Blueberries	7,825	21,701	31,737
Cherries	57,069	111,257	110,505
Peaches	65,269	46,859	16,000
Strawberries	74,671	281,508	213,815
Total of all fruits & berries	429,884	675,163	650,313

Table 11 Trend of Per Capita Consumption of Fresh and Frozen Strawberries in the United States (Bain and Hoos, 1963).

Year	Fresh berries[1/]	Frozen berries[2/]
	(pounds)	
1939-41	3.2	.45
1945-47	1.6	.45
1949-51	1.7	.95
1955-57	1.5	1.49
1959-61	1.4	1.22
1965-67	---	1.25[3/]

1/ On farm weight

2/ Processed weight which is generally 17-21 percent greater than delivered fresh weight.

3/ Estimated based upon population and the production and import data from Tables 9 and 11.

to additional factors. For one thing, starting in the early 1960's, strawberries imported from Mexico have become significant.

Denisen et.al., 1969, pointed out that from 1967 to 1968, import of fresh strawberries from Mexico increased 32 percent. At the same time, the import of frozen berries was even more significant, amounting to about 25 percent of the U.S. production. Concern was also expressed by Antle, 1970, who pointed out that in 1969, import of frozen berries amounted to about 30 percent of the U.S. production of frozen berries and the acreage in Mexico in 1970 was up 25 percent over the 1969 acreage. He stated that the import duty is 2 cents per pound and the price at the U.S. border is 22 cents per pound for 30 pound tins of grade B or better berries. The trend is clearly evident in Table 12. In the past several years, the decline in U.S. production approximately equals the increase in imports. Booster, et.al., 1969, brought the situation into perspective when they noted that the production imported from Mexico is exceeded only by the production of California and the production of Oregon.

Two factors indicate that competition from Mexico may not be an extremely important factor. First, data provided by the Agricultural Marketing Service, USDA, show most imports from Mexico occur from mid November to mid March when California berries are not in significant production. Second, in April, 1972, American Fruit Grower stated that Mexican strawberry growers were planning to voluntarily reduce exports to the United States to 81 million pounds -- down 10 million from 1971 and down 26 million from 1970. Although the quantities don't agree exactly with the 1970 production listed in Table 12, they indicate that, at least in the short run, this particular aspect of the problem is lessening.

None the less, California production of strawberries is very much subject to change depending upon competition from other products. This fact was treated in detail by Dennis and Sammet, 1961, when they studied regional competition in the frozen strawberry industry and concluded that either development of cost reducing techniques which would be applicable to conditions outside of California or a 10 percent increase in labor costs in California compared to other growing areas would virtually destroy California's competitive position.

Table 12 Imports of Strawberries, Most of Which Come From Mexico. (American Fruit Grower, January, 1971).

Year	Imports		
	Fresh Market	Frozen	Total
	(thousands of pounds)		
1965	6,400	53,900	60,300
1966	13,100	85,700	98,800
1967	21,700	74,700	96,400
1968	29,000	75,200	104,200
1969	44,300	89,800	134,000
1970 1/	39,900	117,800	157,700

1/ January thru July only.

Supply and demand as they influence prices are certainly an integral part of any competitive business. Prices received by growers from strawberries can be highly variable between years, within each year, and between fresh market and frozen berries. The season average price on packed and loaded basis FOB shipping point for fresh market was 23 to 26¢ per pound for the period 1968 to 1971. Prices of processing crops on the basis of returns at the processing plant door, were about 15¢

for the same period. Generally, fresh market berries start at a premium price early in the year and as production increases the price declines. Information on seasonal fluctuation of prices is given in Table 13.

Table 13 Monthly Average Prices of Fresh and Freezer Strawberries For 1968 Through 1971.

	Average price[1/]							
	1968		1969		1970		1971	
Month	Fresh	Frozen	Fresh	Frozen	Fresh	Frozen	Fresh	Frozen
	(Cents per pound)							
January								
February								
March	33.8		37.9		33.4		41.2	
April	20.1		27.0		22.5		27.9	
May	24.2	16.5	23.1	15.5	24.0	16.5	23.9	14.0
June	21.8	16.5	25.3	16.0	24.4	16.5	25.6	14.0
July	24.4	16.5	28.5	17.0	23.2	16.5	25.0	14.0
August	23.3	16.5	23.2	17.0	20.6	16.5	25.6	14.0
September	23.6	16.5	18.6	18.0	21.2	16.5	21.4	14.0
October	27.0	16.5	25.0	18.5	21.4	16.5	23.2	14.0
November								
December								
Season average	23.1	16.5	25.0	17.0	23.7	16.5	25.9	14.0

[1/] Fresh fruit prices taken from Fresh Market Vegetable Prices, Crop Reporting Board, SRS, USDA and freezer berries prices from Fresh Fruit and Vegetable Federal-State Market News, San Francisco Weekly Fruit Reports, C & MS, USDA.

4. THE STATE OF HARVEST RESEARCH

Research is currently underway in several states on development of harvest equipment and breeding varieties adaptable to machine harvest. This rather extensive research has been initiated in an effort to reduce production costs and has considered both horticultural and engineering aspects.

Plant Breeding Prospects for breeding new varieties with concentrated ripening were discussed by Denisen et al., 1969. They express the opinion that plant breeders can do much to aid the engineer, indicating that in Iowa State trials 49 and 92 percent of the fruits ripened at one time. A typical situation for four varieties is given in Table 14. Dr. Bringhurst, has indicated in personal conversation, that varieties are currently available for California conditions which will yield about 5 tons per acre on a single pick basis.

Plant breeders have been active, also, in developing varieties which produce firm fruits that are well suited for mechanized handling and long conic fruits well adapted to processing. An example of this is the Tufts variety developed for California conditions and discussed in Section 3.2.

Strawberry Cappers Development of a capper which will remove the stem, calyx, and sepal is considered to be an aid to harvest since capping the fruit for the freezer market slows the pickers and, therefore, adds to the cost of harvest (see footnote Table 7). Hanson, 1972, stated that "It is quite apparent that if we are to lift the sagging strawberry industry in Michigan it will be necessary to concentrate efforts on a machine to remove caps". If we analyze the activities of a hand picker we note that with berries going to the freezer, capping is an essential task. Booster et al., 1969, discuss the research on development of mechanical harvesters.

Table 14 Degrees of Concentrated Ripening Available in Selected Varieties (Denisen, et al., 1969).

	Usable ripe fruits in 1-pick as percent of fruits in classification			
Variety	Primary	Secondary	Tertiary	Quarternary
23-6214	75	97	62	8
26-6215	94	94	39	9
Cyclone	100	81	38	0
Midway	75	96	61	5

Table 15 Classification of Mechanically Harvested Strawberries (Summarized from Booster, et al., 1969, Booster et al., 1970, and Quick, 1970)

	Percent of Total Fruit	
Classification	Average	Range
Fruit recovered (Mach.)	65	24 - 90
Fruit picked & dropped (Mach.)	20	7 - 30
Fruit not picked (Mach.)	15	2 - 46
Damaged (Mach.)	40	20 - 53
Damaged (Hand)	12	7 - 17
Unusable damaged (Mach.)	10	6 - 12
Unusable damaged (Hand)	0	0
Overripe (Mach.)		18 - 25
Overripe (Hand)		14 - 29
Ripe (Mach.)		47 - 53
Ripe (Hand)		58 - 60
Color inception (Mach.) (20-80% pink)		6 - 16
Color inception (Hand)		13 - 21
Green (Mach.)		4 - 19
Green (Hand)		0
With caps and stems (Mach.)	33	28 - 51
With caps or stems (Mach.)	53	3 - 4
Without caps or stems (Mach.)	2	5 - 13
Clusters (Mach.)	12	5 - 13

They note that the hand picker searches out fruits, selects fruits to be picked, sorts out obviously defective fruits as he picks, places good berries in containers and carries containers to a central location. If the fruit is destined for processing the picker also removes the cap (calyx) and stem (peduncle). Any machine system will have to accomplish these same tasks and since mechanization is usually first initiated on processing fruit, the capping and stemming operation is an important factor.

To be successful under California conditions a capper must be effective on fruits which are concave in the calyx area as well as on fruits which are convex. Booster, et.al. 1969, reviewed progress on development of machines for strawberry production and reported that several capping machines have been developed using the principle of counter-rotating rollers to grasp the stems and caps and pull them from the berries. They state that such machines are 80 to 90 percent effective on varieties adapted to machine harvest, but only about 20 - 55 percent effective on varieties not well adapted. Problems were encountered with a tight - clasping calyx or with a recessed calyx. They suggest two possible solutions, 1) orienting and stemming individual berries and 2) quick freezing and then removing stems and calyx by a brushing, tumbling, or buffing action. The first approach is being researched at the University of California, Davis with encouraging results (Dooley, et.al., 1972) and the latter approach is being researched at Oregon State University (Booster, et.al., 1970, and Kirk, 1972) also with encouraging results.

Mechanical Harvesters Harvester development was discussed by Booster, et.al., 1970, and Quick, 1970. Data are presented in Table

15 which indicate good results can be obtained with non selective harvest, but potential problems, including fruit injury and fruit maturity, exist.

Principles of most strawberry harvesters under development to date can be classified as stripper type or cutter-bar type. Preliminary research by Hoag and Hunt, 1966, indicated strippers are an effective way to remove strawberries and proper finger spacing was found to be important. The stripper combs used by Hoag and Hunt were positioned perpendicular to the bed and were moved forward and upward to produce the desired combing action. Fingers were 3/8-inch diamter, about 3-inches long, and spaced from 1/4 to 1/2-inch apart. Nelson and Kattan, 1970, used a similar type of stripper. Their stripper consisted of a comb-brush arrangement which was part of a continuous elevator conveyor. In addition to fingers similar to those used by Hoag and Hunt, the stripper had bristles positioned between each row of fingers for the purpose of gently dislodging berries lying on the ground. The comb-brush conveyor was enclosed in a pneumatic duct so high velocity air could lift the fruit from the ground to a position in front of the comb-brush stripper. Results indicated that once-over mechanical harvest was feasible and recovery was 50 to 80 percent on selected varieties.

Buchele and Denison, 1968, also tested a stripper which was similar to that used by Hoag and Hunt but had 10-inch long, 1/4-inch diameter tines spaced 5/8-inch apart. The total forward movement of each comb thru the bed was limited to the length of the tines. Yield loss was estimated to be 25 percent and the authors noted that most of the premium "king" or primary berries were lost due to damage or spoilage of the overripe fruit during harvest. They suggest that a possible solution is to first pick by hand and then harvest once-over by machine.

A stripper type unit developed by Booster, et al., 1969, had a pair of combing reels positioned parallel to and along the outer edges of the bed. The reels were counter rotating and the combs moved inward toward the center of the bed and upward thru the plants.

A vibrating stripper unit was developed in Iowa (Quick, 1970) to provide a means for keeping the individual fingers or teeth in the crop and to simplify design. Vibration of the stripping teeth was reported to improve penetration of the plants, to impart an oscillating conveyor action to fruits, and to aid in fruit separation. A freely rotatable roller was positioned under the teeth to hold down stems and thus assist removal. Air blown over a sheet metal shield conveyed the removed fruit from the stripper unit to a mechanical conveyor.

Several cutter-bar type harvesters have been under development, also. One such unit developed by Booster, et al., 1970, cut off the plants just above the ground and had a pneumatic cleaning system for separation of leaves and other debris. Cutter bar harvesters also were developed by a group of Oregon growers, by Iowa State University, and by the University of Guelph (American Fruit Grower, June, 1971). The Iowa State and Guelph units both used netting over the bed. The netting was lifted by the harvester and the cutter bar clipped fruit stocks and peticles beneath the net which collected the severed fruit. Both machines were reported to have potential for harvest of fresh market fruit since little injury to fruits occured.

North Carolina State University researched the possibility of using what they called an air-suspension vibration principle to achieve selective removal of mature fruits. Long steel rods were vibrated and moved thru the stems of fruits held up by air-suspension. It was

reported that impact of the rods against the fruit stem induced resonant vibration and caused stem failure (American Fruit Grower, June, 1971).

In addition to the above listed harvester development, Louisiana State University and several manufacturers have research underway and the University of Guelph has two other harvest units under development (American Fruit Grower, June, 1972; Booster, et al., 1969). At least one inventor has considered a harvester which detects and selectively removes red berries (Rasmussen, 1968).

The above reports indicate that reel-type stripper harvesters can move down the row at about 1/4 mph. The Iowa vibrating stripper can operate at about 1/2 mph and the cutter-bar harvesters can go about 3/4 mph, with the possible exception of the two which cut under netting.

Harvest Aids Several attempts have been made to utilize labor aids to improve the efficiency of hand harvest. One approach has been to use long conveyor belts which extend across many rows and convey fruits from pickers walking behind the belts to a central grading station located on the propelling vehicle. Success has been limited because, 1) pickers cannot work individually on a piece rate so they lose incentive, 2) fast pickers are limited to the rate the conveyor moves which is primarily determined by the rate of slow pickers (the conveyor cannot be moved too far ahead of any worker), and 3) pickers must work fast enough to make up for any non productive workers such as operator and graders who are not necessary in conventional harvest where pickers sort fruit as they pick.

A variety of personnel carriers have been researched. Workers sit, kneel, or lie on the carriers as they pick. Some units are for one worker, some for two, and a few have more than two workers. Increases in worker output are reported to be about 20 to 30 percent (Wolf, 1971).

5. FEASIBILITY STUDY

The procedure used in this study was to first make a detailed feasibility study as outlined by Asimow, 1962. Based upon the current situation, an analysis of the needs was made to determine the real need. Then the system was identified complete with the system boundary, outputs desired to meet the real need, inputs necessary to accomplish desired outputs, inputs from the environment, and undesired outputs resulting from the inputs. Solutions were synthesized and analyzed to determine those that do not seem to be feasible with current knowledge.

Solutions which were found to have potential based upon the feasibility study were then studied in more detail in an effort to predict which systems have good potential for reduction to practice. A simulation model was developed to aid in this study.

5.1 Needs analysis

Experts have stated the need in a variety of ways. Thor and Mamer, 1969, expressed the belief that farm wage rates will continue to increase, the supply of laborers willing to do seasonal labor will decrease, and the uncertainty of workers and wage rates will increase. They state that the only practical solution to the farm labor problem is to develop production and harvest methods which will greatly reduce the need for labor. Other solutions to the farm labor problem are thought to cause a substantial increase in food costs which would hurt more people than it would help, particularly people having low income. It would have an adverse affect on people working in support industries as well, since higher prices would increase foreign competition and further decrease production. The opinion has been expressed that mechanization leads to unemployment of hand laborers. While Thor and Mamer don't disagree, they point out that fruit and vegetable production was developed in an environment of sufficient seasonal labor and low wage rates which leave many farm laborers in poverty. It is the opinion of Thor and Mamer that "In the long run a completely systematized, mechanized agricultural industry will benefit all of the people of the nation". Crosby, 1969, stated "Any fruit or vegetable that is not mechanized in respect to production, harvesting, and handling will not remain as an important agricultural product in the future".

Research effort on mechanization of harvest is being expended in at least seven states and Canada on the belief that the opinions expressed by Thor and Mamer and Crosby are correct. The major thrust has been on the harvest operation since it represents a substantial portion of the production costs. Larson, 1969, states that one half to three fourths of the production cost is for harvest.

Available evidence presented in Chapters 3 and 4 indicates that a real need exists for improved production systems which will decrease or, at least, slow the rate of increase of production costs, and reduce labor requirements, particularly during the peak of harvest.

5.2 System Identification

The system under consideration is illustrated schematically in Figure 6. Although major concern rests with harvest related operations, the system includes all operations involved in producing and harvesting strawberries. Cultural operations including bed preparation, planting, soil fumigation, mulching, fertilization, irrigation, etc. are considered along with harvest and preparing fruit for shipment. The needs of the worker and, where applicable, the processor are included along with the needs of the grower. The system does not include manufacture or

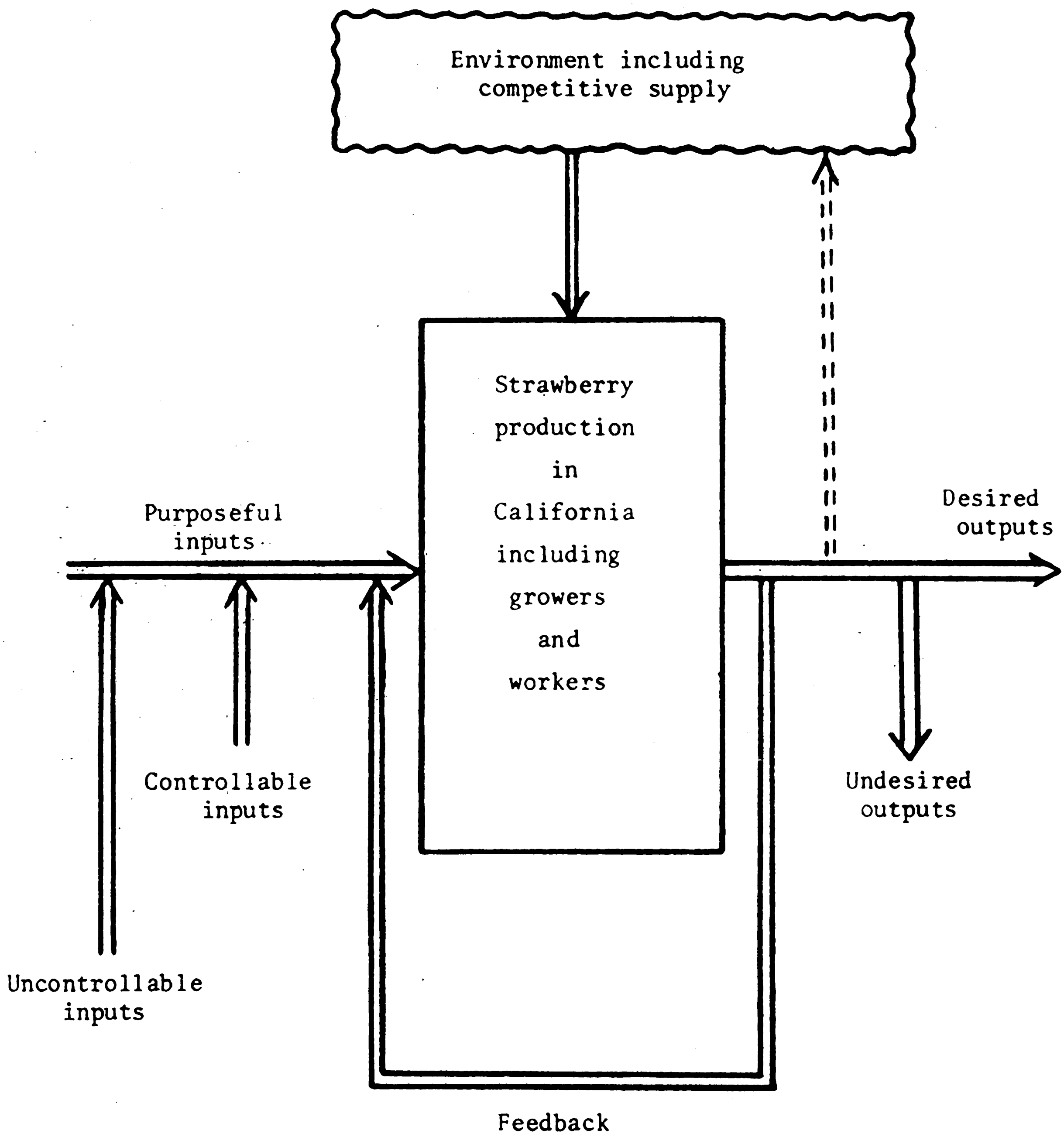


Figure 6 Schematic Diagram of System

production of supplies, equipment, etc. nor does it include shipment to the fresh market. Harvest is taken to be the most important factor since, as discussed in Section 3.3, the cost of harvest, at best, is equal to the total of all other costs of production, and can reach an amount equal to 3 times the other costs. Also, much of the harvest cost is for relatively short term labor which is not too desirable for either the grower or worker. The labor costs associated with other production operations represent less than one third of the cost of these operations and the labor is more permanent in nature.

Activity analysis Based upon the established needs and identification of the system, the following outputs, inputs, and constraints are considered relevant.

Desired outputs:

1. Stabilize the need for labor (reduce peak need).
2. Maintain fruit quality at a satisfactory level considering maturity, damage, decay, etc. (quality $\approx$ current quality).
3. Maintain a stable income for growers (income $\geq$ current income).
4. Increase the productive capability of laborers (harvest rate $\geq$ 3 trays/hour).
5. Provide a stable, reasonable income for laborers (total annual income per worker > current total annual income).
6. Reduce cost of production or at least slow rate of increase (costs $\leq$ \$7079.00/acre).
7. Maintain price received by grower at a competitive level (price $\leq$ 25¢/lb for fresh market & 15¢/lb for processing).
8. Reduce price to consumer or at least slow rate of increase (price $\leq$ current retail price).

Undesired outputs:

1. Cause possible unemployment.
2. Reduce salable yield (average yield < 16 ton/acre).

3. Increase sorting costs (dollars/ton).

4. Create adverse social consequences.

5. Reduce number of small farms.

6. Increase capital outlay (capital invested > $1,400/acre).

7. Increase opportunity for spread of disease due to incomplete harvest.

8. Cause odors due to decaying fruit left after incomplete harvest.

Purposeful inputs:

A. Controllable

1. Human energy (man-hours/acre).

2. Capital outlay (dollars/acre).

3. Operating costs including maintenance, depreciation, etc. (dollars/acre).

4. Plants (variety, number per acre).

5. Cultural practices (mulching, soil fumigation, and shaping).

6. Fertilization and irrigation (equal to current input).

7. Date of planting.

8. Post harvest procedures (cooling, in field freezing, capping, etc).

B. Uncontrollable

1. Foreign competition.

2. Competition from other states.

3. Competition of other crops.

4. Size and location of market place.

5. Taxes (sometimes inflated in populated area).

Environmental inputs:

1. Prices.

2. Solar energy in the form of light for photosynthesis and heat.

3. Weather.

4. Smog.

Constraints on outputs:

1. Grower profit greater than or equal to current profit.

2. Farm labor wage rate greater than or equal to current rate.

3. Berries harvested for fresh shipment must have caps, stems, and essentially no damage, dirt, or foreign matter.

4. Berries harvested for processing must have caps and stems removed and no severe damage.

5. Tonnage harvest for freezer less than or equal to current capacity.

Constraints on inputs:

1. System must use existing varieties or ones which are considered to be realistic to breed.

2. Labor supply less than available in past.

3. Soil fumigation essential for disease control.

4. Financing available for new equipment provided cost can be amortized in about 5 years due to obsolescence.

Although all of the outputs, inputs and constraints listed are considered to be a part of the system under study, some are not included in the simulation model. Justification for omitting these factors is based upon the lack of available data to include a meaningful consideration and that for the purpose of this study an inordinate amount of time would be required to develop the needed data. Factors which are not included in the model are believed to be of relatively minor importance. For example, the desired output of reducing or at least maintaining the price to the consumer can be affected by supply and demand but is not considered in this analysis. Smog and weather certainly have an effect on production and field operations but were considered only to the extent that they affect historical data used in the study.

Problem statement:

The problem is to develop a mechanized production system which has a reduced peak labor requirement and reduces or stabilizes production costs. Mechanization of harvest or improved harvest techniques are of particular concern since the peak labor force and a relatively large portion of the costs are associated with the harvest operation. However, the scope of the problem includes the entire production because 1) cultural changes are undoubtably essential for successful improvement of the harvest operation and 2) the objectives are to decrease peak labor requirements, stabilize employment, and increase profits for the complete production.

Criteria for evaluation of feasible alternatives:

Two sets of criteria were selected for evaluation of the alternatives judged to be feasible. One criterion was intended to reflect the needs of the growers and one for the workers. Omission of a criterion for consumer interests does not imply that such interests are not important. Rather, it was assumed that if both labor demand and grower costs are stabilized, then consumer needs would likely be met. The needs of the freezer are best represented by constraints. Total frozen fruit should remain constant, delivery of fruit to the freezer should be reasonably uniform, and quality of fruit should be maintained.

The criteria established to evaluate the primary desired outputs to meet grower needs were increasing annual income, reducing peak labor requirements, and decreasing risk associated with the stochastic nature of the production. For comparison purposes grower income was considered as marginal income, where marginal income = [(income from proposed system - cost of harvest with proposed system) - (income from current system -

cost of harvest with current system)]. Risk was defined as probability of marginal income being less than zero. In addition to the above individual criteria, a composite grower criterion, G, was defined as follows:

$$G = \left(\frac{\text{marginal income}}{\text{risk x max. no. of workers}}\right)$$

To meet grower needs G should be maximized.

Criteria which will accurately reflect the output desired by workers are difficult to establish. For the purpose of this study, it was assumed that workers would benefit from an increase in total man-hours of work available and from an increase in the average man-hours per worker (average work period). Income is of concern to the worker, but assuming all menial labor jobs have the same pay rate, the two factors listed reflect worker income. Thus, the above two factors were selected as criteria and a composite worker criterion, W, was defined as:

$$W = \left(\text{Man-hours per year x } \frac{\text{man-hours per year}}{\text{maximum number of workers}}\right)$$

where W is to be maximized. In addition, the standard deviation of the number of workers was evaluated. Although these criteria were defined as the worker criteria, they may also be considered as a concern of the growers. In a report prepared for the Manpower Administration, U.S. Department of Labor, Cargill and Rossmiller, 1970 (pg. 38), it was recommended that: "Studies be undertaken to develop appropriate policies whereby, the losers who are required to make substantial social and economic adjustments due to technological change can be compensated out of the rewards flowing to the gainers from those changes".

5.3 Synthesis of solutions

The types of changes which might be made in the strawberry industry

to bring about the desired outputs can be classified as follows:

1) Horticultural practices

2) Harvesting practices

3) Farm size and location

4) Labor force recruitment or working conditions.

The first two types of changes are considered to be independent of the last two and further are considered to be the only types of changes relevant to this study. This does not imply that significant improvements can come only from the first two types of changes, but rather provides a practical limitation of the scope of this study.

Some potential changes in horticultural or harvesting practices might also be independent of each other; but in other cases changing harvesting practices may only be possible if horticultural practices are changed. Thus, synthesis of new solutions can be classified as:

1) New cultural practices with unchanged harvest practices.

2) New harvest practices with unchanged cultural practices.

3) New harvest practices and new cultural practices.

It was recognized that not all growers are using the most productive cultural practices so one solution is to extend the use of the most up to date techniques. For example, in Section 3.0 it was noted that small farms generally produce low yields, so one obvious solution for these growers is to adopt practices which result in high yields. Although this solution could be important to many growers, it will not be considered here. In personal conversation, growers in the Central Coast region state that in the summer of 1972 many acres of berries were planted in a single row rather than a double row to make berries more accessible for hand harvest. This too represents a potential solution,

but will not be considered in this study.

Solutions which concentrate on the harvest operation seem most likely to provide the desired outputs, particularly in view of the fact that harvest labor and harvest cost are the primary labor and costs needs for the production of strawberries. Therefore, attention will be directed toward synthesis of solutions which are centered around modification of harvest. Consistent with the previously discussed limitation, six general types of solutions have been conceived as having potential for meeting the desired output. These solutions are:

1) Once-over machine harvest of berries using varieties tending to have one concentrated ripening period.

2) Multiple nonselective machine harvest of berries using varieties tending to have multiple concentrated ripening periods.

3) Selective harvest of berries by machine using current everbearing varieties.

4) Hand harvest of all early, premium priced, berries and a portion of berries produced later in season with peak production being harvested, in part, by machine using one of the solutions outlined above under 1, 2, and 3.

5) Harvest aids in the form of personnel carriers designed to carry one or two pickers or tray carriers designed to carry full and empty trays for a small number of pickers.

6) Complete revision of the production system to something other than the conventional bed with harvest.

<u>Once-over machine harvest</u> Mechanical harvest on a once-over basis would meet several of the desired objectives, but on the surface it seems likely that it would produce substantial undesired objectives most significant of which seems to be yield loss. It is plausible, however, and as such is deserving of further analysis. Breeding of an acceptable variety would be essential.

<u>Multiple nonselective machine harvest</u> This proposed solution, like the preceeding solution, could meet several of the desired objectives.

One major difference is that it appears that loss of yield could be reduced. This solution would require development of a detachment device which, although nonselective, would permit multiple harvest. One possibility is a device that cuts fruit stalks (cymes) which have several large mature fruits. Different stalks would be cut during subsequent harvests. This approach would be aided by breeding a variety which has relatively uniform fruit maturity on each fruiting stalk. A second possibility is a device which picks by size and as such is not selective by maturity, but would permit multiple harvests.

Selective harvest by machine Selective harvest by machine would, in theory, nearly eliminate the substantial reduction of salable yield. Technological problems are undoubtably greater, but solution is plausible. Selective harvest would require a detection device which could search out fruit and sense color, softness, or possibly ease of detachment in order to identify mature fruits. In addition, a device would be needed to detach selected fruits.

Combination hand and machine harvest This proposed solution has considerable appeal in that premium priced berries can still be picked by hand in a selective manner with no loss of salable yield. However, as labor demand reaches a peak it can be supplemented by machines. All (or most) fruits harvested by machine could be used for processing, reducing the problem of loss of salable yield expected to occur with machine harvest. In addition to supplementing hand harvest during the peak season, machines might be used to harvest low quality, low yield fields near the end of the season when hand pickers may find other employment more desirable.

Harvest aids The use of harvest aids has good potential for easing

the task of the worker without causing extensive unemployment. Cargill and Rossmiller, 1970, recommend use of mechanical aids to reduce physical strain and thereby create a more positive work environment. Fruit quality should be maintained, but cost of harvest might not be reduced as much as with other more mechanized solutions. The harvest aid being considered would carry one or two pickers. Personal conversation with industry personnel indicate recent trials using many pickers on one machine were unsuccessful. Machine speed was limited by the slowest pickers. A new practice which might be used in conjunction with a harvest aid is the harvest of entire fruiting stalks which have mostly mature fruits. This practice might be used just during peak harvest to accelerate picking.

Revision of production system Changing the conventional production system to one which is designed specifically to facilitate hand or machine harvest may provide the most unique solution. The use of single row beds instead of double row beds as discussed previously in this section would be one possible change. However, for the purpose of this study, two more substantial changes are proposed. First is the use of a strawberry wall as initially conceived by Fridley and Henderson, 1966. This concept is illustrated in Figure 7. The objective is to provide a growing situation where the berries are separated from the leaves rather than being at least partially covered as they are in the conventional method. Adjacent walls would be parallel, but different orientations might be used in some fields to induce harvest peaks at different times and thereby spread out the total production peak. The strawberry wall seems plausible, but several technological questions arise.

The second proposed change is the use of a low horizontal trellis

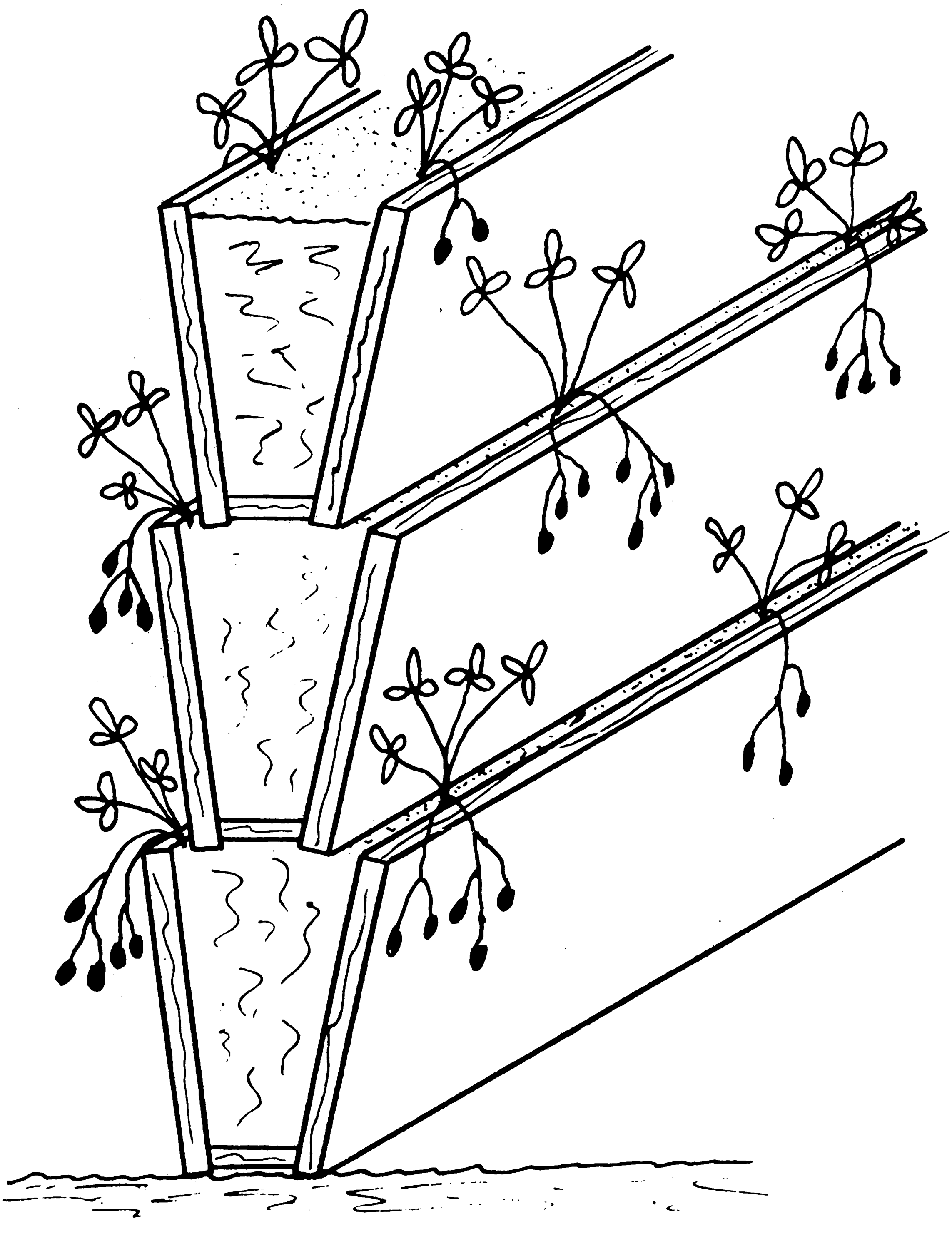


Figure 7 Schematic Diagram of Strawberry Wall

to hold fruit stalks (cymes) above the ground and thereby facilitate harvest. This concept was suggested by J. Dooley, graduate assistant at University of California, Davis. The system would consist of a single row bed with a "T" or "Y" trellis which would extend about two to three inches above the ground and be about twelve inches wide. The trellis would be fabricated of wood, steel, or plastic posts which would support a series of about four to six wires.

5.4 Realizability and practicability analysis

The feasibility of the proposed solutions was evaluated by making an analysis of economic practicability, physical realizability, financial realizability, and social realizability. Economic practicability accounts for the ability of the grower to recover his investment. Because of obsolescence associated with newly developing systems, it was assumed that a grower should be able to ammortize his equipment in about five years or less. Physical realizability includes two factors--1) the degree to which the desired outputs (except cost factors which are considered separately) could be expected to be realized assuming the proposed systems were developed and 2) the confidence level of accomplishing the developments considering anticipated physical and biological problems to be solved. The confidence level can be considered to be the probability of success in solving problems encountered.

The procedure used for analyzing the interrelationship of economic practicability and physical realizability was as follows: First, estimates were made of machine capacity and cost and then the salable yield needed to give a breakeven situation with hand harvest was determined. Second, a value judgment was placed on each possible solution in terms of how well it satisfied the desired outputs and avoided undesired

outputs. Third, the probability of achieving the parameters set up in the economic analysis was established considering 1) engineering technology and 2) horticultural technology. Finally, an expected gain was estimated based upon the relative values from step two and the probability of success from step three.

Financial realizability reflects the ability of the growers to finance proposed solutions (a grower may find it impossible to raise sufficient capital even though the solution can be shown to be economically sound). Social realizability considers the expected acceptance of proposed solutions by society including the laws and institutions of society. Social factors listed as outputs in the activity analysis of Section 5.2 are not considered under social realizability.

Economic practicability Information is limited so a detailed economic analysis of proposed solutions is difficult at best. However, experience on similar problems and data that are available (see Section 4) makes estimates possible.

Table 16 gives results of economic analysis of once-over machine harvest, multiple non-selective harvest, and selective harvest. The procedure used to establish the values tabulated was to first estimate machine speed, usage, and cost, labor required, and the number of days between picks. Based upon these numbers, costs were established and the total machine cost per acre computed. Given the fact that the total cost (machine cost plus the opportunity cost associated with loss of salable yield) for machine harvest must not be significantly greater than the cost of hand harvest (about $4,000 per acre), the salable yield which must be harvested was calculated assuming a total potential yield of 20 tons per acre.

Table 16 Summary of economic analysis of once-over machine harvest, multiple nonselective machine harvest, and selective machine harvest.

Item	Estimated values: Once-over	Multiple Nonselective	Selective
Machine speed	50 ft/min	25 ft/min	20 ft/min
Machine capacity (40-inch beds)	2 acres/day	1 acre/day	0.8 acre/day
Machine usage	50 days	100 days	100 days
Days between picks	--	10 days	7 days
Acreage/season	100 acres	10 acres	5.6 acres
Machine price	$15,000	$15,000	$18,000
Machine cost/season (5-year life)	$ 3,000	$ 3,000	$ 3,600
Tax and interest	$ 1,500	$ 1,500	$ 1,800
Labor (2 men @ $3/hr)	$ 3,000	$ 6,000	$ 6,000
Cost/season/machine	$ 7,500	$10,500	$11,400
Mach. cost/acre	$ 75	$ 1,050	$ 2,050
Opportunity cost/acre[1/]	$ 3,925	$ 2,950	$ 1,950
Total cost/acre	$ 4,000	$ 4,000	$ 4,000
Salable yield/acre	11.1 tons	13.3 tons	15.6 tons

[1/] Opportunity cost is the value of fruit loss resulting from mechanical harvest compared to hand harvest. Fruit value was assumed to be 22¢ per pound which is a weighted average price computed from average prices in Table 13 assuming 3/4 of fruit is fresh and 1/4 frozen. It was assumed that the opportunity cost/acre was $4000 minus the machine cost/acre.

NOTE: Estimates of machine speed, capacity, usage and price; days between picks; and labor use are based upon information discussed in Chapter 4 and upon the experienced judgement of the author. Other values are calculated.

It is noted that acreage capacity for a once-over harvest is 100 acres per season compared to 5 to 10 acres per season for multiple pick machines, but the computed increase in yield loss offsets the gain. Also, additional sorting costs which would be required to remove damaged and poor maturity fruits is not included. This would further increase the cost in proportion to fruit loss. Any cultural changes which may be required are assumed to cost the same as current cultural operations.

Cost of the proposed solution of using a combination of hand and machine harvest depends upon the proportion of fruit picked by hand and when machines are used. Cost would be higher if machines were used only during the peak harvest rather than being used throughout the season. For this analysis, machines were assumed to be used to harvest only one-half of the daily production on those days when machines would be used. All early fruit and late fruit were assumed to be hand picked. Further, it was assumed that all fruit picked by hand went to the fresh market and all the machine picked fruit was sold as freezer fruit. From Table 16, machine harvest costs for multiple nonselective harvest would be $3,000 depreciation and $1,500 taxes and interest. Machine labor would cost about $2,000, depending upon the actual duration of the peak. For 10 acres, this gives harvest cost $650 per acre for machine harvest plus $2,000 for hand picking half of the crop. The value of potential fruit loss was assumed to be 22¢ per pound. Thus, it would be necessary to harvest a salable yield of 10 tons per acre by hand picking and about 6 tons per acre by machine harvest to achieve a total cost of $4,000 per acre, the cost of conventional hand pick.

Economic analysis of harvest aids is complicated by the fact that effectiveness is a function of such factors as season length, the specific worker on the machine, the yield per picking, amount of plant foilage, and the pay system used for harvest. For the purpose of this study cost of a one man unit was estimated to be $750. Worker output was assumed to be increased by 20 percent (Wolf, 1971) and fruit loss was assumed negligible. In Section 3.4 it was noted that hand pickers average 2 to 3 trays per hour or about 20 trays per day. An increase of 20 percent would give an increase of 4 trays per day. Data in Section 3.3 show a picking cost of about $1.00 per tray which indicates a potential savings in labor costs of $4.00 per day. For a 100 day season, the savings would be $400 per season which would be economically practicable. The preceeding computation assumes the grower would derive financial gain so as to pay for the aid. This may be valid for growers who pay on an hourly basis. However, growers who pay on a piece rate would not likely find it practical to reduce the rate to recover their costs. Mr. J. Mehlschau,[1] development engineer, University of California, Davis, has suggested that the solution might be to have growers buy machines and rent them to pickers. The picker should be willing to pay for use of a device which would increase his output, and hence his income, while making his job easier. Income from the rent would provide the grower with a return on his investment. Some growers pay a base rate of about $1.75 per hour plus a bonus of 15 to 20 cents per tray. Under this pay system growers might simply buy the machine and let pickers use them. Pickers would gain by having easier work and increasing their bonus pay. Growers would gain by having more fruit picked. In any case, the investment per acre would be about $1,250 per acre assuming one man on the machine would pick about 2,400 crates per season. (crates and trays are synonymous)

[1]Personal communication.

If the trellis system provided a 20 percent increase in harvest rate (the same as estimated for the harvest aid), the potential savings would be about $275 per season (computed from picking cost shown in Table 7). Thus, depending upon the validity of assumptions, the trellis system is economically practicable.

wire -- 50,000 feet per acre (4 wires for 12,500 feet of row per acre)

T's -- 2,500 per acre (spaced 5 feet apart)

labor-- 8 man-hrs. per acre

Associated costs are:

wire @ 1/2¢ per ft -- $250 per acre per season

T's @ $100/thousand -- $250 per three seasons or $83 per acre per season

labor @ $3 per hr -- $24 per acre

total cost -- $357 per season per acre

If the trellis system provided a 50 percent increase in harvest rate (the same as estimated for the harvest aid), the potential savings would be about $275 per season (computed from picking cost shown in Table 7). Thus, depending upon the validity of assumptions. The trellis system is economically practicable.

Meaningful analysis of the economics associated with the strawberry wall is quite difficult since many changes would be required and little information is available upon which to base assumptions. Horsfield, 1969, made a preliminary economic analysis and his results (Table 17) are considered to be valid for use in analysis. It is to be noted that the actual acreage involved depends upon spacing, height, and plant density of the walls. For example, spacing plants one foot by one foot on a 6-foot wall spaced ten feet apart or 3-foot walls spaced five feet,

would give about 50,000 plants per acre as compared to 25,000 plants per acre in conventional summer plantings. Thus, the system represented in Table 17 would occupy five acres so the total cost would be (5,683 + 15,240 + 16,090)/5 or $7,400 per acre. Tables 6 and 7 give a cost of $7,079.00 per acre for conventional production. Furthermore, even if the yield per plant is reduced, the strawberry wall may have more total yield than conventional plantings due to the increased plant population. Also, any possible benefits of some form of mechanical harvest are not included. In conclusion, based on available information, the strawberry wall is economically feasible, but obsolescense is a risk which must be recognized.

To summarize the economic analysis, combined hand and machine harvest, harvest aids, the trellis system, and the strawberry wall show promise, but economic savings are likely to be small. Feasibility of once-over machine harvest can be achieved only if a high yielding variety with concentrated ripening became available.

Physical realizability The research discussed in Chapter 4 provides some insight into the potential gains and the problems associated with mechanical harvest, particularly once-over harvest. Labor requirements for harvest on a once-over basis are very low, but harvest of all berries by machine would no doubt cause unemployment of many workers who have a reasonably long work period. However, supplementing hand harvest by some machine harvest could provide a means of reducing peak labor requirements without causing undue unemployment. Use of harvest aids and revised production systems also have potential for providing moderate reduction of labor requirements without leading to excess unemployment.

Table 17 Estimated Costs of Production Using Strawberry Wall For Operation Growing 250,000 Plants (Derived From Horsfield, 1969).

Item	Investment: Initial cost	Investment: Life	Labor	Misc.
	(Dollars)	(Yrs)	(Dollars per year)	(Dollars per year)
The Structure	$50,500	12	--	--
Soil sterilization	2,000	15	--	1,500
Filling wall & planting	--	--	400	250
Removing old plantings	7,800	10	1,120	--
Fertilization	--	--	--	1,370
Weed control[1/]	--	--	--	--
Removing runners	--	--	500	--
Pruning	--	--	620	--
Irrigation	6,000	12	--	250
Pest control	--	--	--	620
Harvest[2/]	2,000	8	12,600	12,000[3/]
Total investment	68,300	--	--	--
Total costs on yearly basis assuming 10% of investment for interest and taxes	5,863	--	15,240	16,090

[1/] Weed control is assumed to be virtually eliminated.

[2/] Harvest is assumed by hand, but a form of harvest aid is included.

[3/] Cost of crates

Yield and fruit quality are significantly reduced by once-over harvest. Multiple harvest would reduce the yield loss and could improve fruit quality by a small amount. Selective harvest would cause some mechanical damage, possibly as much reduction of quality as other means of mechanical harvest. However, selective harvest would increase yield by harvesting berries at a desirable maturity. In all probability, berries harvested by machine would be acceptable only for freezing. Therefore, since nearly three-fourths of California's strawberries go to the fresh market, supplementing hand harvest with machine harvest could be more practical for growers and would reduce the yield loss and help maintain quality. Use of harvest aids and revised production systems should cause little quality or yield reduction. With a harvest aid, harvest is still done by hand. Preliminary tests conducted with strawberry walls have shown some wind damage to berries and some potential of per plant yield loss due to shading and poor distribution of irrigation water.

Subjective value judgements of the relative merits of the proposed solutions are shown in Tables 18 and 19 considering the grower and social points of view, respectively. In each case, three outputs were considered and an overall average computed considering all three to have equal importance. This, of course, is subject to debate but was considered valid for this study.

Each of the proposed solutions have technological problems which must be solved before the solution can be realized. The difference in physical complexity was accounted for by assigning a confidence level to successful development of each proposed solution, i.e., the probability of achieving the state assumed in the preceeding economic analysis,

(Table 20). For this purpose it was assumed that engineering technology and horticultural technology are both necessary and that they are independent events. Therefore, the probability of success, P, is equal to the product of engineering confidence level, P_e, and horticultural confidence level, P_h, or $P = P_e \cdot P_h$. The overall expected gain for the grower, E_g, is then the product of P and the overall value judgement from Table 18. The expected gain for the worker, E_w, is P times the overall value judgement from Table 19. It is noted that a marginal value judgement of 4 times a .5 probability of success would give an expected gain of 2.0. Thus, any expected gain of about 2 or less has very doubtful feasibility.

The information presented in Tables 18, 19, and 20 indicate that systems which rely solely upon machine harvest are not likely to be feasible. However, supplementing hand harvest with machine harvest may be realizable. Seemingly, this possible solution would be realized most likely if machine harvest were multiple, nonselective. Use of harvest aids or a revised production system seem to have the best chance of realizability but may not be particularly effective in meeting a primary grower need of reducing labor requirements.

Financial feasibility Use of machines to harvest all berries has poor feasibility due to both economic practicability and physical realizability. Therefore, only combined hand and machine harvest, harvest aids, and revised production systems are considered here.

Combined hand and machine harvest would require use of one of the mechanical harvest systems discussed. Since once-over harvest seems to be a poor choice on the basis of economic feasibility, attention is directed to the other proposed solution where the machine makes multiple

Table 18 Value Judgement of Relative Merits of Proposed Solutions in Terms of Achieving Growers Desired Outputs and Avoiding Undesired Outputs

Outputs[1/]	Relative degree to which outputs were estimated to be realized[2/]							
	Once over	Multiple nonselective by cymes	Multiple nonselective by size	Selective harvest	Hand and machine	Harvest aids	Revised prod. systems trellis	Revised prod. systems wall
Desired:								
Reduce peak labor needs	10	8	8	8	7	4	4	4
Maintain fruit quality	5	7	6	6	9	10	10	9
Undesired:								
Reduction of yield	3	6	5	7	8	10	10	9
Overall average	6.0	7.0	6.3	7.0	8.0	8.0	8.0	7.7

[1/] Outputs related to cost were not included since they are part of the economic practicability and financial realizability analyses. Other outputs which appear in the activity analysis but are not listed here were considered to be impractical to place a meaningful relative value at this point.

[2/] Outputs are rated such that 10 implies high achievement of desired outputs and no change of undesired outputs. A rating of 4 implies marginal acceptability for California conditions.

Table 19 Value Judgement of Relative Merits of Proposed Solutions in Terms of Achieving Socially Desired Outputs and Avoiding Undesired Outputs.

Outputs	Relative degree to which outputs were estimated to be realized[1/]							
	Once over	Multiple nonselective		Selective harvest	Hand and machine	Harvest aids	Revised prod. systems	
		by cymes	by size				trellis	wall
Desired:								
Stablize worker income	4	6	6	6	9	8	8	8
Undesired:								
Unemployment	4	4	4	4	8	9	10	10
Fewer small farms	5	6	6	6	9	10	9	8
Overall average	4.3	5.3	5.3	5.3	8.7	9.0	9.0	8.7

[1/] Outputs are rated such that 10 implies high achievement of desired outputs and no change of undesired outputs. A rating of 4 implies marginal acceptability for California conditions.

Table 20 Confidence Level For Development of Proposed Solutions and Expected Gain From Their Implementation

Item	Rating							
	Once over	Multiple nonselective		Selective harvest	Hand and machine	Harvest aids	Revised prod. systems	
		by cymes	by size				trellis	wall
Confidence level for engineering[1/]	.80	.70	.60	.40	.70	.80	.90	.70
Confidence level for horticulture[1/]	.30	.50	.60	.90	.70	1.0	.90	.80
Composite confidence level[1/]	.24	.35	.36	.36	.49	.80	.81	.56
Grower expected gain	1.6	2.5	2.3	2.5	3.9	6.4	6.5	4.3
Social expected gain	1.2	1.8	1.9	1.9	4.3	7.2	7.3	4.9

[1/] Confidence levels correspond to probability of success and as such have a maximum value of 1.0 and minimum value of 0.0

passes through the field and can handle the harvest of about 10 acres. In this situation the estimated investment is $15,000. Assuming one-fourth of a growers acreage is harvested by machine, a grower having 40 acres would be in a position to finance this magnitude of investment ($375 per acre) and small growers could undoubtably depend on employing the services of a custom operator who could justify the investment by harvesting for a number of small growers.

Adoption of either mechanical aids or the trellis system should not pose any particular financial problem. Both proposed systems can be implemented over an extended period of time. That is to say, a grower could distribute his investment over any desired number of years. Harvest aids would require an investment of about $1,250 per acre if aids were used for all picking. Trellis production would require about $524 per acre.

The strawberry wall is in a category by itself and probably the most difficult to evaluate. This system requires rather extensive revision of the current operation; revision which can only be achieved by rather large initial investment. Using the cost data and acreage estimates presented in the economic analysis, it appears that an investment of about $10,000 per acre for the walls would be necessary. Considering the current annual production costs of about $7,000 per acre (Tables 6 and 7), this investment is not completely out of reason, however, obtaining financing would present a substantial undertaking.

Social realizability All four of the systems analyzed for financial realizability are judged to be socially realizable.

Conclusions of feasibility study Based upon the preceding analysis the set of feasible solutions are:

1) Combined harvest using both hand pickers and machine harvest. Hand pickers would work throughout the season and machine harvest using some type of multiple pick would supplement hand pickers during peak season.

2) Use of harvest aids to facilitate hand harvest.

3) A trellis system which would support fruiting stalks and make fruit more accessible for either hand or machine harvest.

4) A strawberry wall whereby berries would be grown on vertical planter boxes placed in parallel rows in the field.

The solutions, harvest aids, and trellis systems, have the highest ratings (Table 20), but this is due primarily to high confidence ratings in the analysis of physical realizability. In terms of the overall average value judgements given in Tables 18 and 19, all four feasible solutions are about equal.

Experimentation with the harvest aid and trellis systems is considered to be relatively inexpensive and is being carried out at the University of California, Davis. Therefore, the balance of this thesis will be directed primarily toward a more complete evaluation of the potentials of combined hand and machine harvest and the use of the strawberry wall. The harvest aid will be evaluated only in terms of the merit of picking entire fruit stalks during the peak season.

6. SIMULATION MODEL

To better analyze the potential of 1) combined hand and machine harvest, 2) harvest of some fruits by picking cymes, and 3) the strawberry wall, a system simulation was undertaken. The simulation approach was chosen because of system complexity and stochastic aspects of production.

6.1 The simulation approach

Simulation, for the purpose of this thesis, is defined as a computational technique for obtaining particular time outputs corresponding to specific assumed inputs and parameters. Manetsch, 1971, indicated that model simulation can be accomplished by a building block approach using the following fundamental set of mathematical operations:

arithmetic operations (+, -, x, ÷)

integration

generation of explicit and nonexplicit functions

generation of time delays

generation of random variants

various logical operations (IF, AND, OR, etc.)

With the elements of the block diagram (Figure 8), and a knowledge of the system, the model can be synthesized by interconnecting elements to give one to one correspondence with the real system. For computation, arithmetic operations are straight forward and integration can be accomplished by an appropriate numerical integration method. In the system being simulated, events occured daily reducing integration to a simple summation of daily outputs.

Routines given by Llewlyn, 1970, were used to generate nonexplicit functions and time delays. Nonexplicit functions were generated with a table function (details given by Llewlyn, 1970, Chapter 4), in which

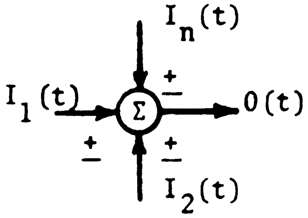
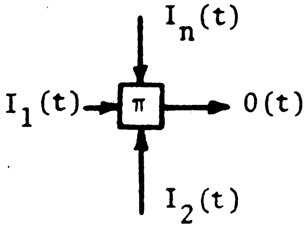
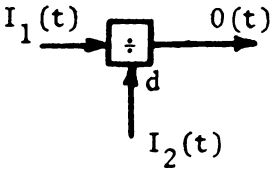
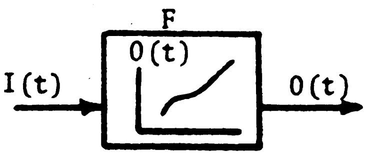
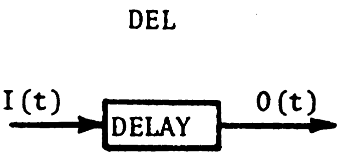
Symbol	Operation	Definition
	Addition	$O(t) = \pm I_1(t) \pm I_2(t) \ldots \pm I_n(t)$
	Multiplication	$O(t) = I_1(t)\, I_2(t) \cdots I_n(t)$
	Division	$O(t) = I_1(t)/I_2(t)$
	Function generation	$O(t) = F\ (I(t))$
	Integration	$O(t) = O(0) + \int_o^t I(x)\, dx$
	Time delay	a) Discrete delay: $O(t) = I(t - DEL)$ b) Distributed or continuous delay $a_k \frac{d^k O(t)}{dt^k} + a_{k-1} \frac{d^{k-1} O(t)}{dt^{k-1}} \ldots + a_o O(t) = I(t)$

Figure 8 Block Diagram Notation (Manetsch, 1971)

data for a relationship are stored and output obtained by interpolation. Time delays can be discrete, or continuous, as defined in Figure 8, with continuous delays being given by a differential equation of order k and average delay D. Continuous delays were simulated by an established delay routine (details given by Llewlyn, Chapter 6). Figure 9 illustrates the continuous delay showing the output for different orders.

Due to limited resources of time and finances, simulation was confined to a macroscopic view of the two major California strawberry production areas. A macroscopic view was used because 1) production patterns for a given area are very similar to the production patterns of individual farms, 2) the goal was to identify harvest systems which would most likely benefit the total industry, and 3) data were readily available by area. An alternative would have been to select specific farms assumed to be typical for each area, but this approach did not seem to have significant advantages for the purpose of this thesis.

The simulation model developed has two primary elements -- a production model and a harvest algorithm. The procedure was to simulate daily production and then simulate harvest by hand or machine based upon certain decision rules. All simulated machine harvest was hypothetical and assumed to be a multiple-pick, semi-selective operation with all machine harvested fruit being freezer quality.

A general flow chart for the simulation is shown in Figure 10. The computer model has a series of four DO loops; one to account for the years of machine life (MY) and provide yearly totals and discounted fixed machinery costs, a second to provide monthly totals and discounted cash costs, a third to compute weekly totals, and a fourth for daily totals. Each year production timing and trend was set randomly as des-

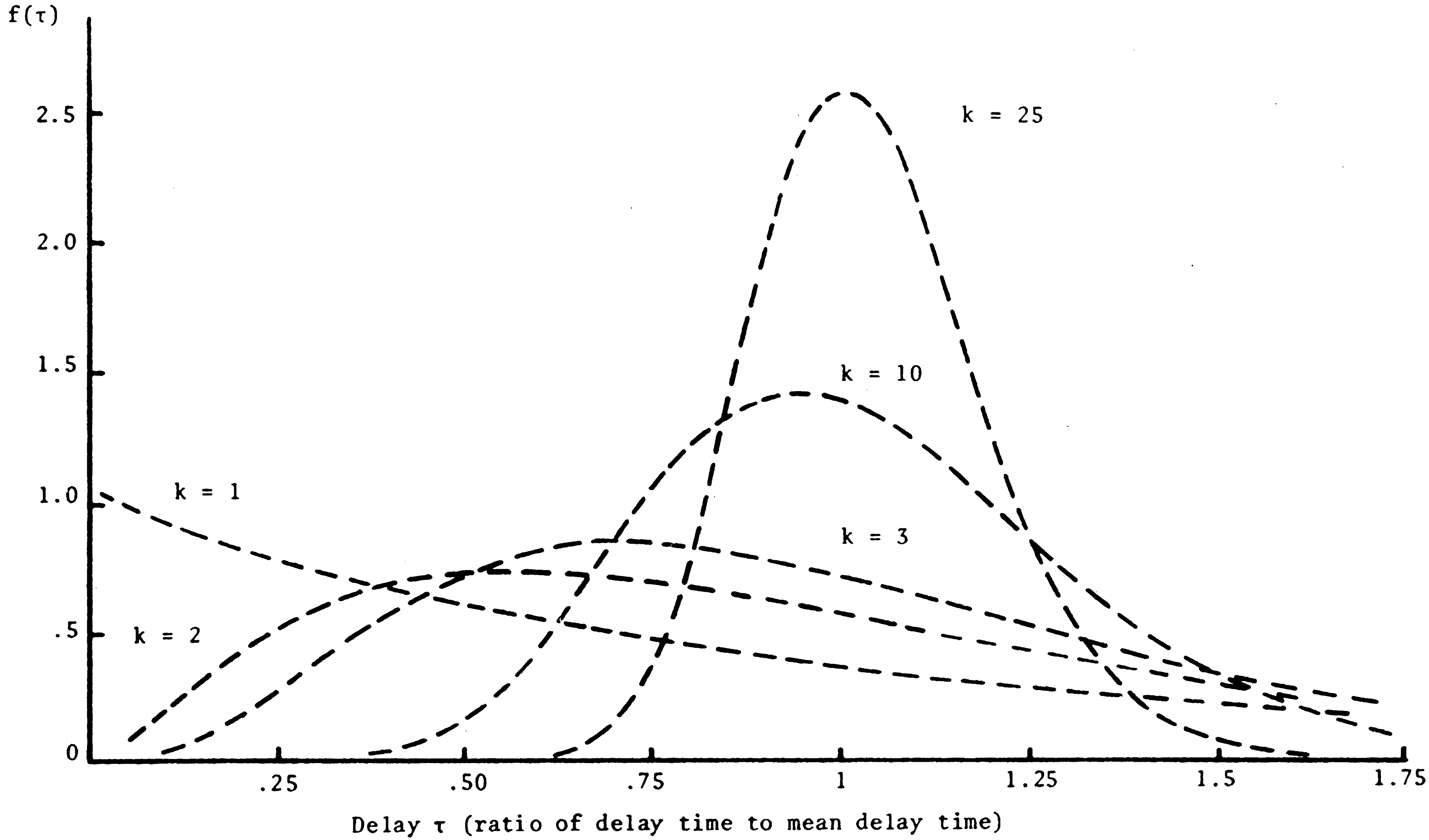


Figure 9 Continuous Delays of Different Orders (Order = k)

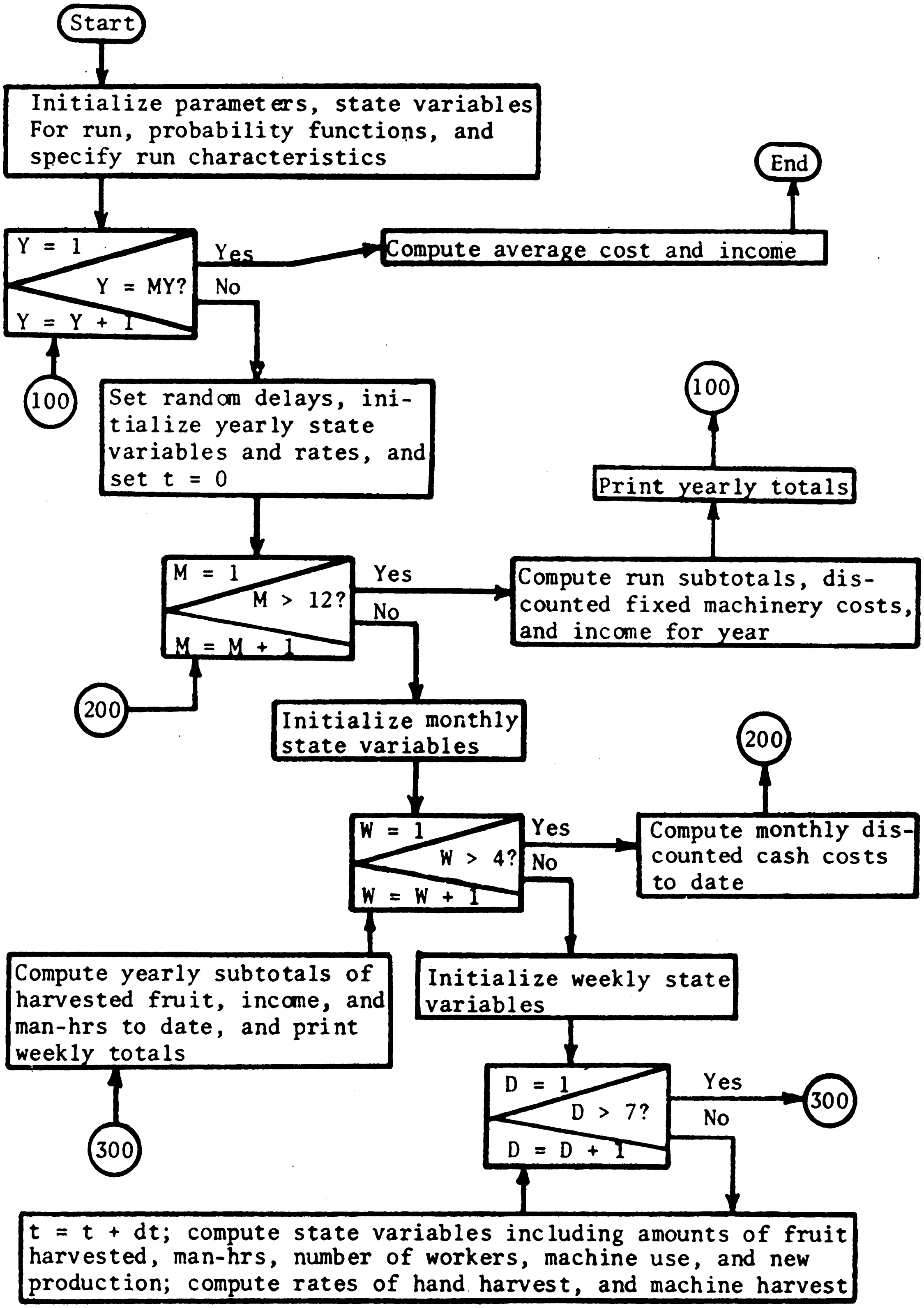


Figure 10 General Flow Chart for Simulation of Strawberry Harvest

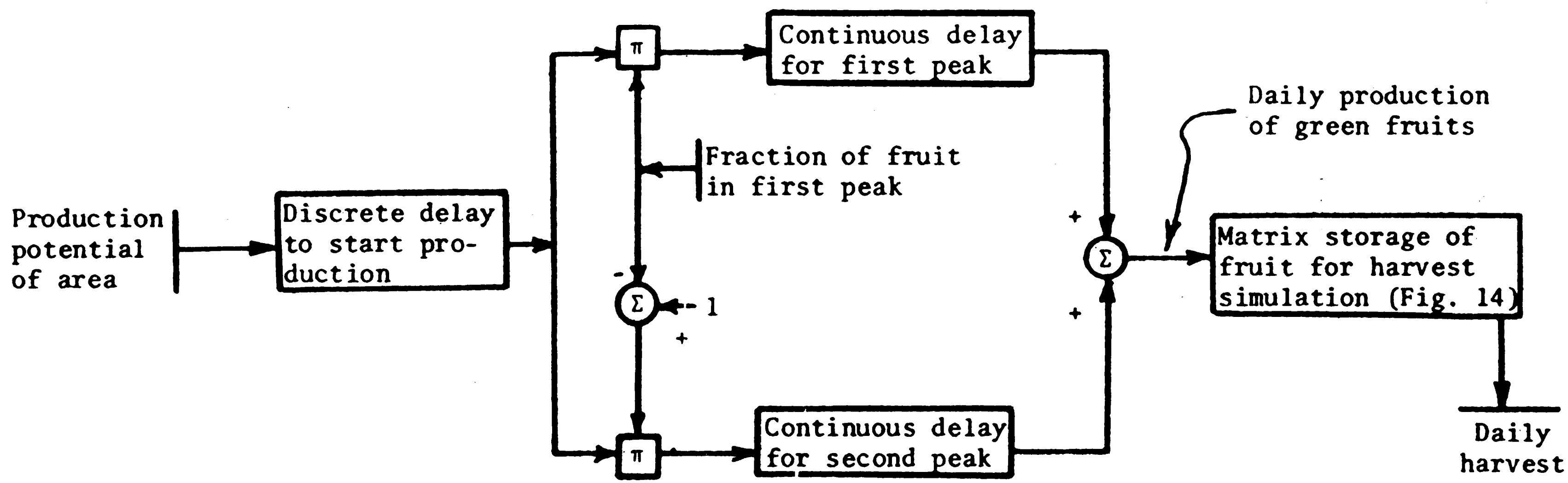


Figure 11 Empirical Model for Macroscopic Simulation of Strawberry Production

cribed in Section 6.2. Amounts of fruit harvested, gross returns, man-hours, number of men needed, and machines used were printed out weekly and yearly. Total man-hours for both hand picking and machine picking and the amount of overripe fruit and green fruit harvested by machine were printed out yearly. Average gross returns, discounted costs, and income were printed out for the period of MY years.

6.2 Berry production models

Two production models were considered. The first is a macroscopic empirical model (Figure 11) which simulates production for an entire area similar to production trends given in Figure 2. This model has an impulse input that has a magnitude equal to the total annual production potential for the area. For the purpose of this study, the impulse magnitude was considered to be a continuous random variable with a pseudo-beta distribution of the form:

$$f(V) = \begin{cases} 0 & V < VL \\ \frac{1}{VH-VL}\left(1 - \cos \pi \frac{V}{VML-VL}\right) & VL \le V < VML \\ \frac{1}{VH-VL}\left(1 - \cos \pi \frac{V - VML}{VH-VML}\right) & VML \le V < VH \\ 0 & VH \le V \end{cases}$$

where,

f(V) = probability density function of V
VH = highest possible value of V
VL = lowest possible value of V
VML = most likely value of V

The impulse passes through a random discrete delay (DEL 1) measured from the beginning of the calander year to the start of the harvest season. The production potential is then split into two parts, one which goes through a distributed delay (DEL 2) to give the first production peak and one which goes through a more lengthy delay (DEL 3) to provide

the second peak. Total daily production potential is the sum of the outputs of the two distributed delays. This production quantity is placed in a matrix for harvest simulation which is discussed in Section 6.3.

The second model, illustrated in Figure 12, has more relation to the growth of berries than does the first. As a result, this growth model can provide more information, could be adapted easily to a particular grower situation, and has potential for incorporation of future field trial results with relative ease. For example, the model can be easily adapted to semi-selective harvest by machine. Also, the delay to bloom could be preceeded by a delay to initiation of fruit stalk growth. Addition of this delay would lend itself to improved simulation of semi-selective harvest of the fruiting stalks (cymes). The growth model would also make possible the inclusion of the effect of weather on rate of growth (the magnitude of the delays). The primary disadvantage of the model is that substantial information about the rate of growth of berries is required to establish the parameters for the various delays. Limited data (Table 21) were collected in an effort to determine the practacability of evaluating these parameters. Results indicate that this approach has merit and can be accomplished. However, extensive testing would be required to establish needed knowledge about effects of weather, varieties, and other factors. Values listed in Table 21 indicate a delay having an order of about 15. Possibly a preferable method of simulating berry growth would be to consider growth as a finite Markov chain with a step transition matrix (Hillier and Lieberman, 1968) like the one given in Table 22. Data in both Tables 21 and 22, however, were taken late in the harvest season and could be substantially different during the peak season.

Table 21 Time for Growth of Strawberries from Bloom to Maturation (Sample Size 145 Berries).

Weeks	Relative frequency
1	0
2	0
3	0.014
4	0.076
5	0.324
6	0.476
7	0.090
8	0.020

Table 22 Transition Matrix for Growth of Strawberries During One Week (Sample Size 145 Berries).

Initial state \ New state	Probability of being in initial state i and moving to new state j in one week.[1/]					
	0	1	2	3	4	5
0	.419	.546	.035	0	0	0
1	0	.490	.392	.054	.064	0
2	0	0	.189	.219	.562	.030
3	0	0	0	0	.603	.397
4	0	0	0	0	0	1

[1/] States are defined as follows: 0 = small fruits which don't yet extend beyond sepals, 1 = solid dark green fruit, 2 = light green fruit showing some white or pink, 3 = pink or white fruits showing some red, 4 = fruits of harvest maturity, and 5 = overripe fruits.

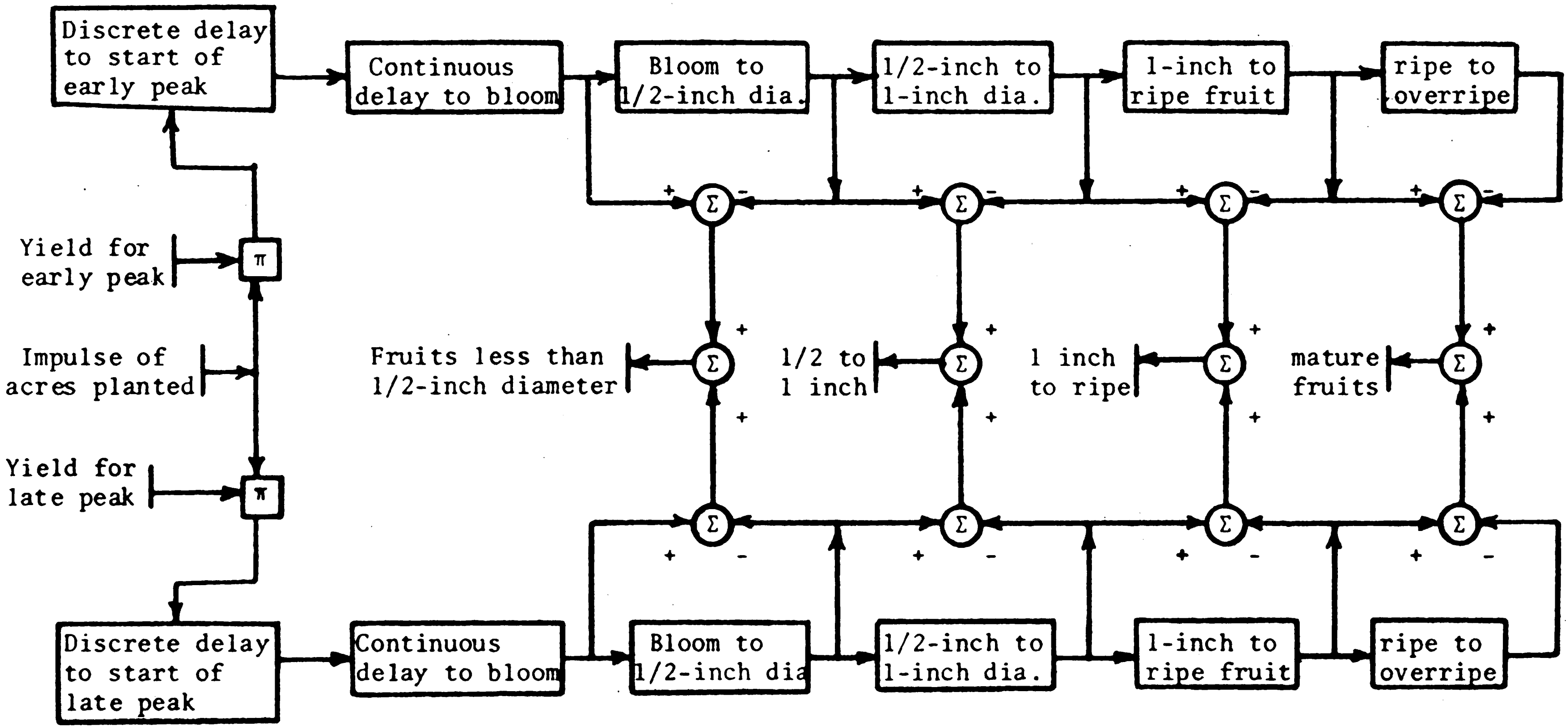


Figure 12 Growth Model Proposed For Simulation of Strawberry Production Based Upon Physical Occurences

Since the purpose of this study was to view the industry as a whole and since time consideration made extensive collection of growth data impossible, the empirical production model illustrated in Figure 11 was used.

The empirical model had three delays which had to be established. Since changes in cultural practices and varieties are made annually, it was not practical to use several years production data to evaluate the delays. Therefore, the discrete delay DEL 1 was set to start production at approximately the time when harvest actually starts. The parameters (order and average delay) for the continuous delays DEL 2 and DEL 3 were set by trial and error so as to provide a production pattern similar to the real trend (Figure 2). The selected orders of DEL 2 and DEL 3 were 5 and 25, respectively, for Southern California and 3 and 15, respectively, for the Central Coast. All three delays--DEL 1, DEL 2, and DEL 3--were assumed to have a beta distribution and for the purpose of this study were defined as a pseudo-beta distribution having the same form as that defined previously for the production random variable. Table 23 gives the lowest, most likely, and the highest values for both the production and delay random variables.

The simulated production pattern for the Central Coast is given in Figure 13 along with actual production data for recent years. For all simulations, DT was set equal to one day.

6.3 Harvest algorithm

Using the empirical model made it necessary to develop a means of simulating field conditions for harvest such that immature, mature, and overripe fruit might be harvested. In other words, simulated machine harvest must have available to it immature fruit and must result in over

Table 23 Parameter Values for Pseudo-Beta Distributions of Total Production and Production Delays

Item	Parameter values		
	Lowest	Most likely	Highest
Production (crates)			
Southern Calif.	4.0×10^6	4.5×10^6	5.0×10^6
Central Coast	6.2×10^6	7.5×10^6	8.5×10^6
DEL 1 (weeks)			
Southern Calif.	7	8	11
Central Coast	12	13	16
DEL 2 (weeks)			
Southern Calif.	5	8	10
Central Coast	4	7	12
DEL 3 (weeks)			
Southern Calif.	11	17	18
Central Coast	17	19	21

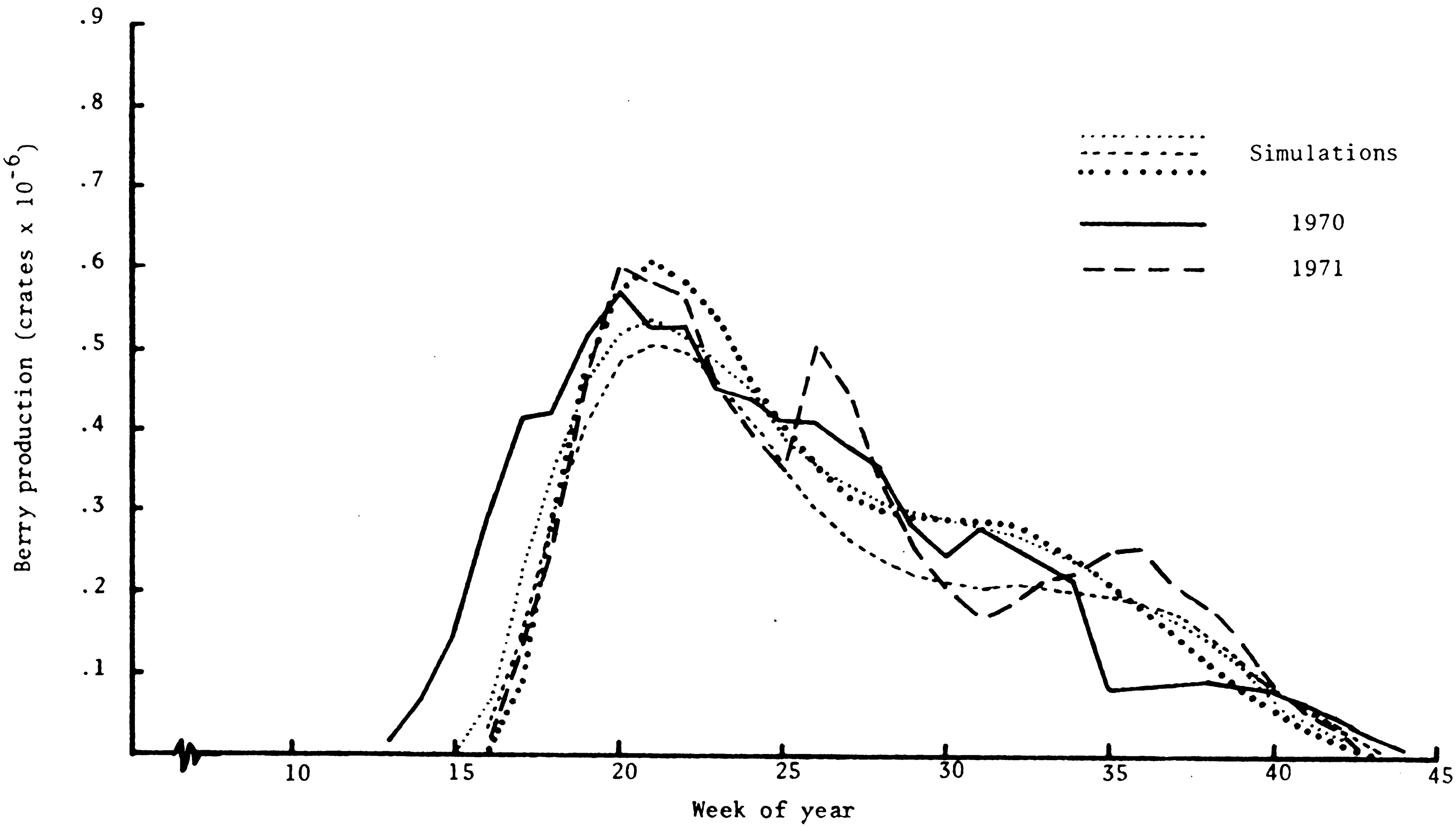


Figure 13 Simulated Production for the Central Coast

mature fruit if removal is incomplete. To accomplish this, the production generated by the empirical model was considered to be production of small immature berries which after a discrete delay would be mature. Figure 14 illustrates the matrix storage of fruit produced and the method of affecting discrete delays.

The entire production on the strawberry wall was placed in the matrix for hand picking since the actual harvest was assumed to be conventional picking of individual berries. For combined hand and machine harvest and for cyme picking, both matrices (Figure 14) were used. Production to be picked by conventional hand harvest was stored in the hand pick matrix and fruits to be picked by either machine harvest or cyme picking were stored in the matrix for machine picking. The distribution of production between matrices was determined by decision rules which 1) established the amount of fruit which could be picked by available labor in the conventional manner, 2) determined if the balance of the production could be harvested by available machines (or machine aids in the case of cyme picking), and 3) assumed a small number of temporary workers could be recruited for conventional hand picking during occasional years when an insufficient number of machines was available for a peak of a few days. The amount of fruit which could be picked in a conventional manner by available labor was assumed to be the same for combined hand and machine harvest and for cyme picking (28,500 crates per day in Southern California and 42,800 crates per day in the Central Coast region). The values used were chosen after preliminary runs indicated that the values provided a significant reduction in peak labor requirements, provided a relatively stable labor demand, and in the case of combined hand and machine harvest, avoided excess freezer fruit.

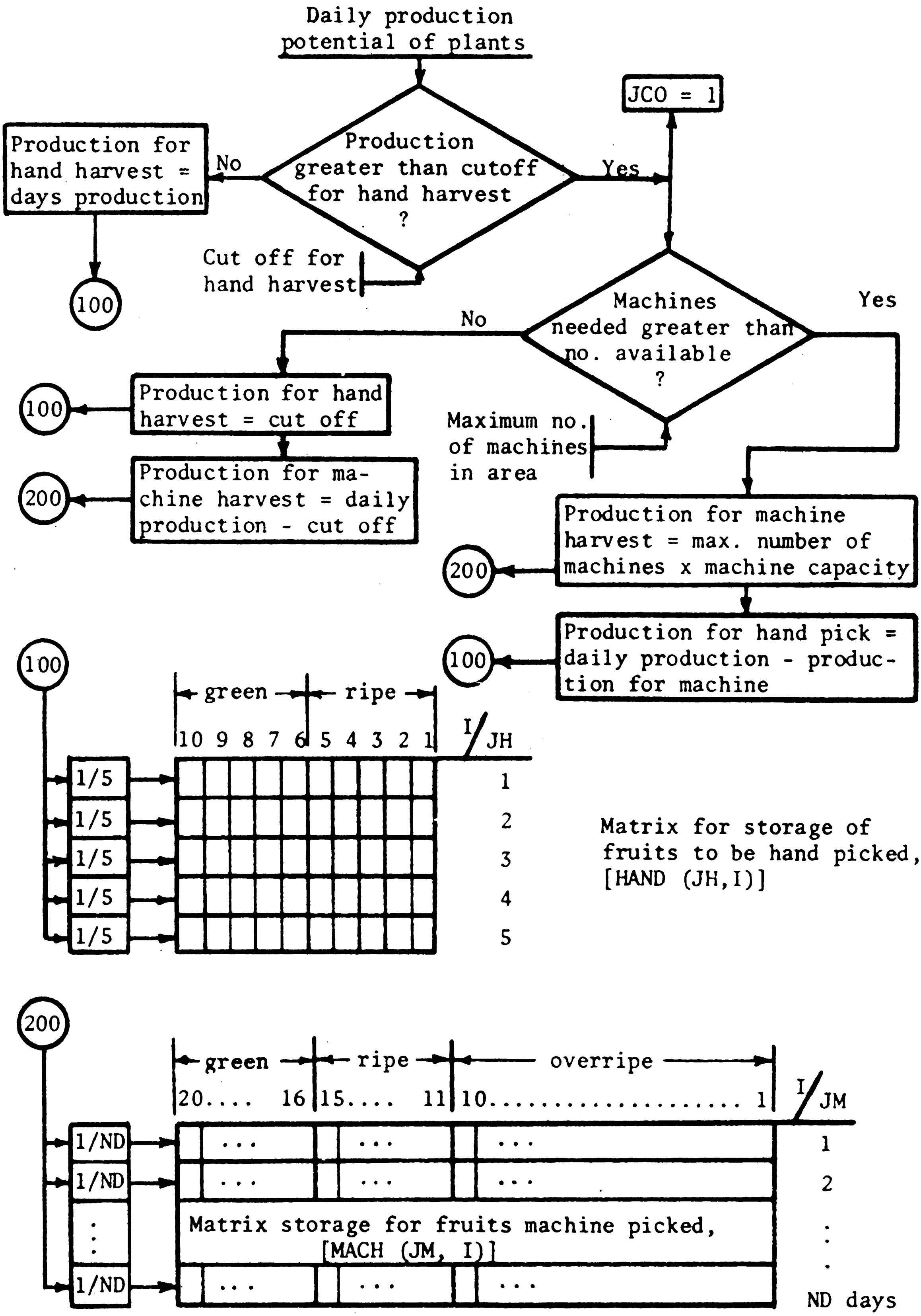


Figure 14 Matrix Storage of Fruit For Harvest Simulation

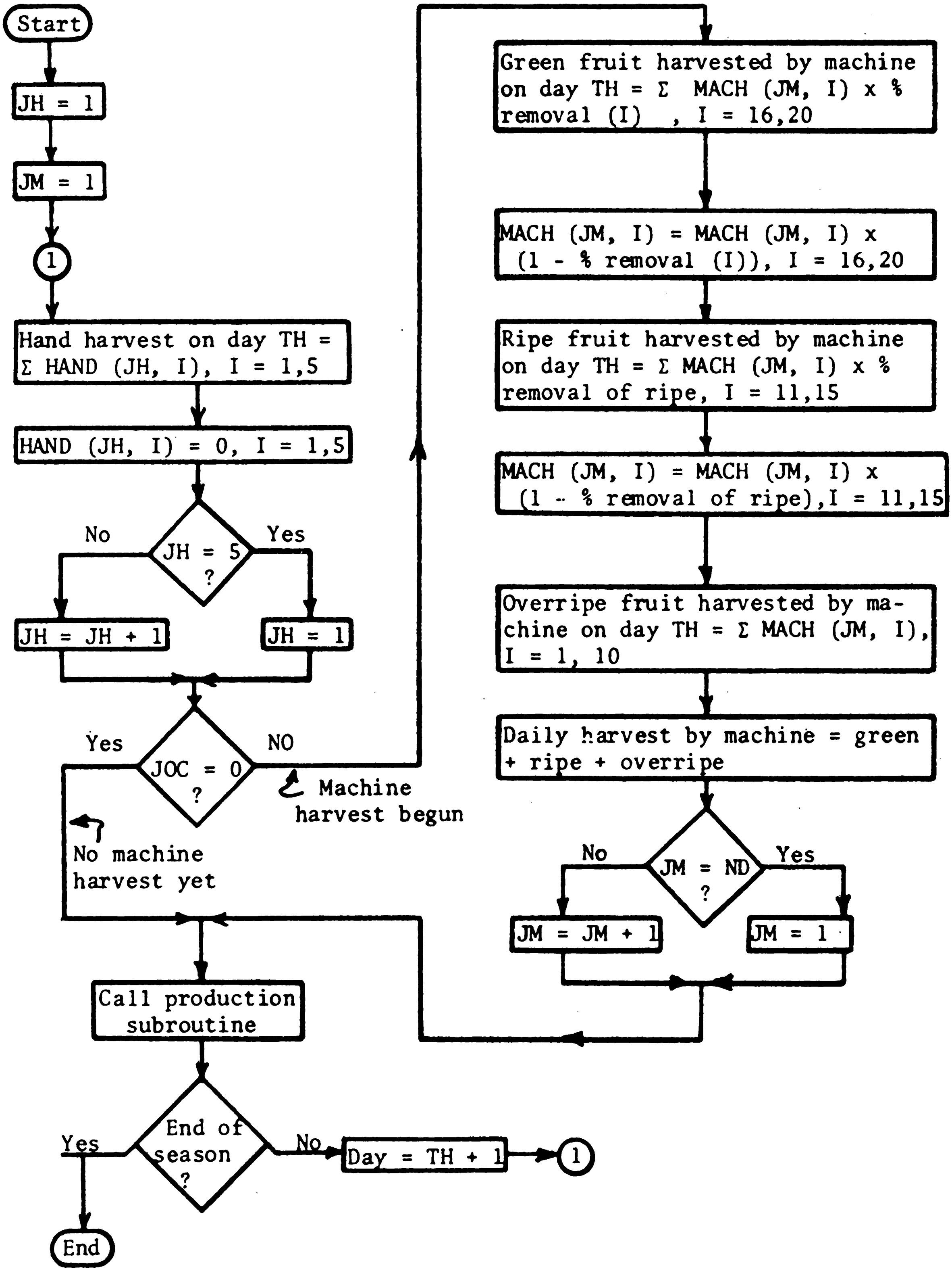


Figure 15 Harvest Algorithm

Each row of a matrix represents the fruits which will be harvested on a given day. The number of rows is such that following harvest of all rows, one row each day, the desired number of days between picks is maintained. Each column of a matrix represents fruits at a given maturity. The five columns on the left represent green fruits, the next five columns represent fruits from minimum to maximum maturity. For machine harvest (or cyme picking), columns are provided for overripe fruit resulting from berries being missed during harvest. During a simulation, the daily production of immature berries was first determined by the empirical production model. Berries to be harvested by hand were distributed evenly between the rows and stored in the left most column of the hand harvest matrix and berries to be machine harvested were stored in a similar fashion in the appropriate matrix. As new fruit was produced and stored in the matrix, quantities stored in each column were moved to the right one column which represented a maturation of one day.

The algorithm for harvest simulation is illustrated in Figure 15. The integer JH is an index for the rows in the matrix for hand picking (Figure 14) and JM is the index for rows in the machine harvest matrix.

Following daily harvest each index was increased by one until the bottom row was harvested and then the index was reset to one. JOC indicated when production was sufficient for machine harvest to commence by being set to 1 (initially 0) when production was greater than could be harvested by hand. For hand harvest, all fruits in row JH, columns 1 through 5, were harvested for fresh market and the stored quantities in the rows of the matrix were set equal to zero. Since it was assumed that hand pickers pick no green fruit, the quantities stored in columns 6 through 10 were not changed by harvest. Machine harvest removed some

immature berries, 90 percent of the ripe berries and all of the over-ripe fruit. Following harvest, the value stored in each element of row JM was reduced by an amount equal to the fruit harvested.

Block diagrams for computing fruit harvested, manpower and machine needs, and gross returns are given for hand harvest and machine harvest in Figures 16 and 17, respectively. The diagram for computation of average annual income based on discounted costs is given in Figure 18. For the purpose of this study, discounted costs were calculated using the general equation

$$DC = \sum_{n=1}^{T} \left[\frac{P(n) + OC(n) + M(n) + T(n) + I(n)}{(1 + r)^n}\right] + C - \frac{S(T)}{(1 + r)^T}$$

where,

DC = discounted cost

n = number of a specific time period

T = total number of time periods

r = rate of return per time period on money invested elsewhere

P = payment on principal

OC = operating cost

M = maintenance

T = tax

I = interest

C = cash down payment

S = salvage value

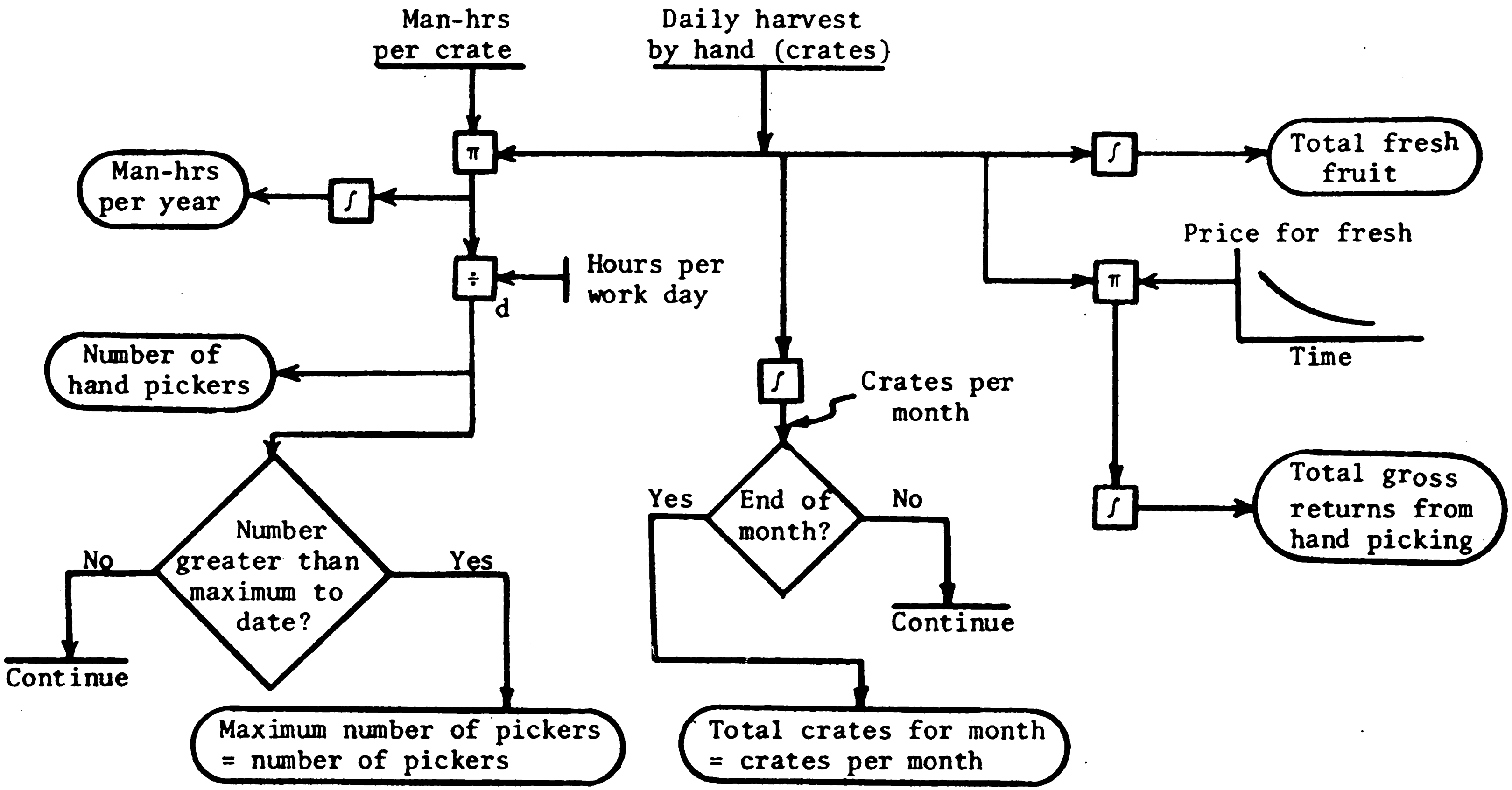


Figure 16 Block Diagram for Computing Fruit Harvested, Manpower, and Gross Returns for Hand Harvest

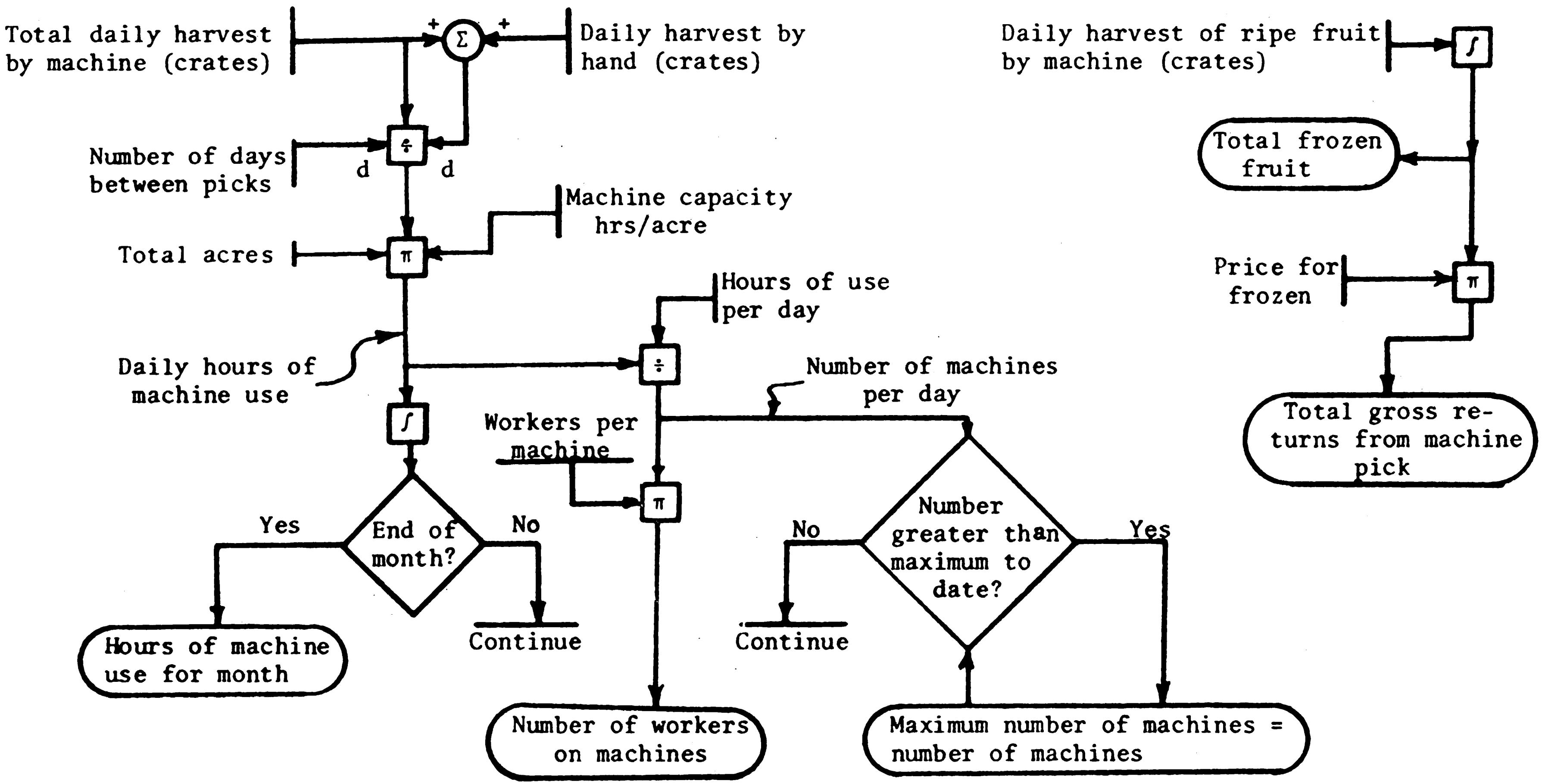


Figure 17 Block Diagram For Computing Fruit Harvested, Harvest Manpower and Machine Needs, and Gross Returns for Machine Harvest

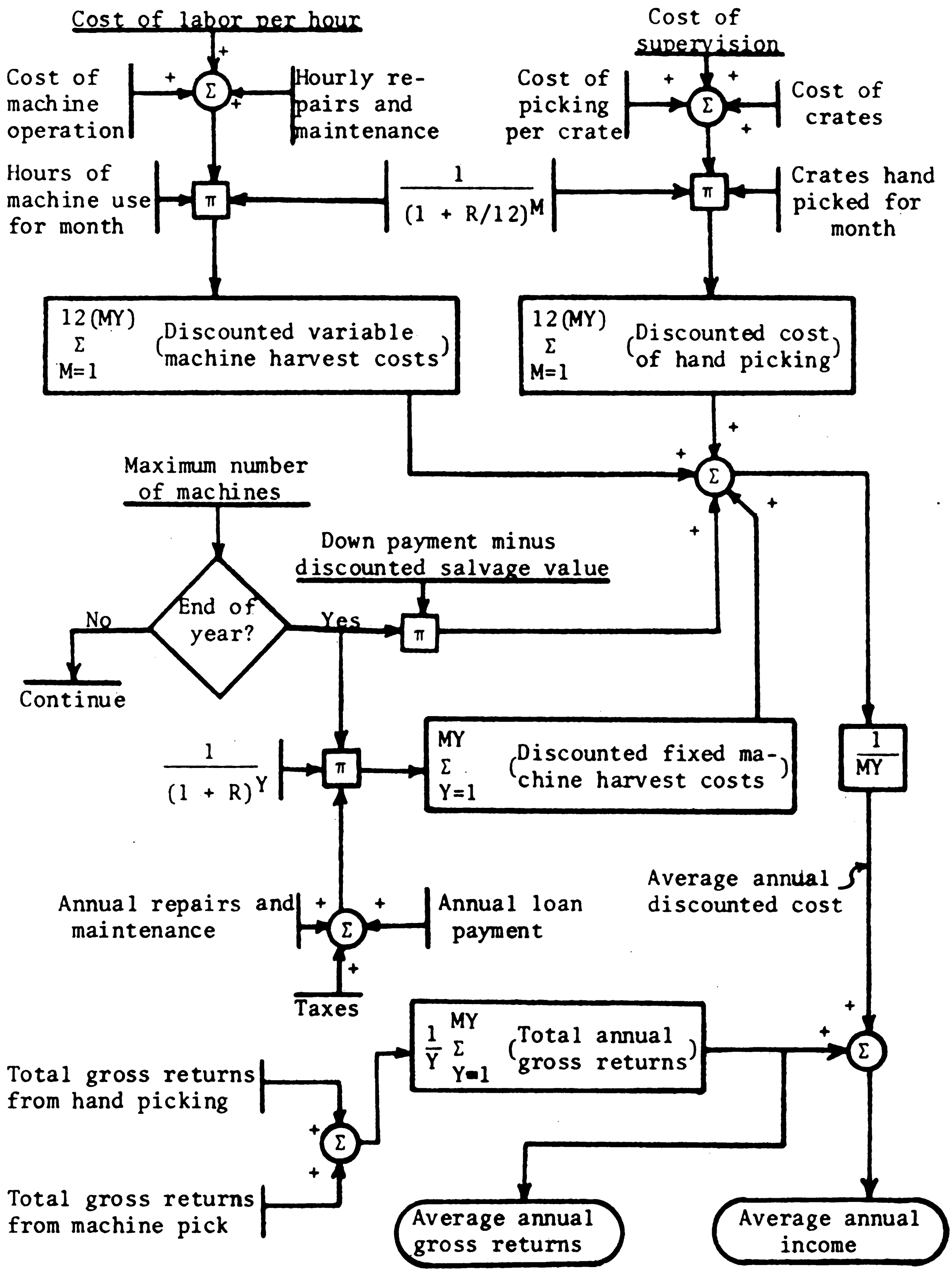


Figure 18 Block Diagram For Computation of Average Annual Income Based Upon Discounted Costs

7. SIMULATION TESTS

The procedure used to evaluate alternatives with the simulation model was to make a series of runs, each of which covered a time period equal to the life of the equipment or facility. Simulation periods of 5 years and 12 years were used for the machine systems and strawberry wall, respectively. Each year the production trends were established from the stochastic inputs. To make direct comparisons of alternatives and to test assumptions, the random number generator was initialized at the beginning of each run. To evaluate risk, eight 5-year runs were made for machine systems and four 12-year runs were made for the strawberry wall.

Several system inputs and parameters were held constant for all runs, both hand and machine. These factors are listed in Table 24. The prices for fresh market berries used in this study are given in Table 25. Price of freezer berries was assumed constant at 15¢ per pound.

Sensitivity analyses were conducted to evaluate several factors associated with the three alternatives. In testing the alternative of combined hand and machine harvest, a sensitivity analysis was made on machine prices, use of machines per day, harvest rate of the machines, the number of machines purchased in each area, the percent removal of green fruit which would have been matured by the subsequent harvest, and the number of days between pickings (picking cycle).

Effect of the following variables was evaluated for the cyme picking alternative: price of machine aids, number of machine aids purchased in each area, price of stemming machines needed to break up clusters and shorten stems of cyme picked fruit, capacity of these stemming machines, daily use of stemmers, the maximum percent of the crop which can be picked by cymes without excess fruit loss, loss of

Table 24 Input and Parameter Values Held Constant Throughout the Simulation.

Factor	Value
Acres in Southern California	2,000
Acres in Central Coast	3,500
Cost of crate for fresh shipment, $ per crate	.40
Items associated with hand pick	
Length of work day, hrs.	8
Man-hrs. per crate to hand pick	0.4
Cost of hand picking, $ per crate	.90
Cost of supervision, $ per crate	.04
Items associated with all alternative systems	
Wage rate for machine operators, $ per hr.	3.00
Wage rate for pickers with aids, $ per hr.	2.50
Total loan on new equipment, % of price	80
Total salvage value, % of price	4
Interest rate on loan, %	8
Discount factor for cost computations, %	6
Cost of annual repairs and maintenance, % of price	5
Tax based on assessed value of 25% actual value, $ per $100 valuation	8.5
Items associated with harvest machines and with stemming machines used in conjunction with harvesting cymes	
Percent removal of mature fruit by harvest machine, %	90
Cost of operating harvest machines, $ per hr.	.25
Cost of hourly repairs and maintenance, $ per hr.	.25
Items associated with harvest aids	
Cost of operating harvest aid, $ per hr.	.04
Cost of hourly repairs and maintenance, $ per hr.	.04

Table 25   Price of Fresh Market Fruit Throughout the Harvest Season.

Date	Fresh market price (cents per pound)
Jan 7	30
Feb 7	20
March 7	19.5
April 7	19
May 7	18.5
June 7	18
July 7	16
Aug 7	15
Sept 7	15
Oct 7	16
Nov 7	17

fruit, and the net picking time required to seek out and pick berries (relative to usual method). Nonpicking time was considered to be the same as for conventional hand picking.

A sensitivity analysis for the proposed strawberry wall was conducted on cost of walls (considered to include materials and installation), a change in pre-harvest costs, the price of picker aids used to carry trays, an increase in production resulting from high plant population, the useful life of the system, and the net picking time relative to conventional hand picking.

The man-hrs required to pick a crate of berries for both the cyme picking method and the strawberry wall was computed from the equation:

$$\text{Man-hrs} = .333R + N$$

where R = net picking time as a fraction of the time for conventional picking (hrs/crate)

N = nonpicking time (hrs/crate) = .0668

This equation was derived from data given in Section 3.4

7.1 Hand harvest simulation

Conventional hand harvest was simulated to provide a basis for comparison and to obtain income data necessary to compute marginal income for proposed harvest systems. Results of a 5-year simulation of hand picking are given in Table 26. Income associated with hand harvest is presented in absolute terms to provide a basis for comparison for the marginal income reported for proposed systems.

7.2 Use of machine harvest to aid hand picking during peak season

Table 27 gives a summary of the simulation results for using machine harvest to supplement hand picking in Southern California. Similar results were found for the Central Coast area. Contrary to the

Table 26 Results of 5 Year Simulation of Hand Picking

Item	5 year average for hand harvest	
	Southern California	Central Coast
Avg. annual income per acre[1/]	$1,720	$1,550
Max. number of pickers for area	2,980	4,080
Avg. number of pickers for area	1,390	1,890
Standard deviation of number of workers for area	1,010	1,250
Avg. annual man-hrs per acre to harvest	1,560,000	2,880,000

[1/] Average annual income is the gross value of fruits at fresh market price less the cost of picking. High value in Southern California primarily is due to an early season when price is high.

feasibility study discussed in Section 5.4, this possible solution was not economically practicable in the stochastic model. From Table 27, it can be seen that marginal income for the reference run was negative even tho the assumptions used were optimistic based on information given in Section 4. Since the assumptions associated with the reference run were optimistic, changes made during the sensitivity analysis tended to cause greater loss of income. It is noted that machine cost, harvest rate, and removal of green fruit greatly affect marginal income and it is unlikely that values as good as those used in the reference run could ever be achieved. For example, limited tests conducted in 1971 indicated that precision picking by size would cause in excess of 6 percent removal of green fruit during peak season and substantially more at times just preceeding or just following peak season. In addition, a high capacity machine is not likely to have good precision.

Therefore, the alternative of using machine harvest to supplement

Table 27 Results of Sensitivity Analysis of Combined Hand Pick and Machine Harvest Over a 5-Year Period (Southern California) to Determine the Effect of Various Factors on Criteria Used to Evaluate Alternatives.

Factor under study	Factor value	Criteria: Max. number of workers	Avg. number of workers	Annual man-hrs required	Marginal income per acre
Reference run[1/]	--	1,930	1,090	1,346,000	$- 7.18
Machine price	$10,000	NC[2/]	NC	NC	-38.90
	$15,000	NC	NC	NC	-70.70
Use per day	13 hours	2,150	1,150	1,378,000	-11.20
	10 hours	2,360	1,210	1,416,000	-15.30
Harvest rate	6 hrs/acre	2,320	1,200	1,464,000	-91.60
	8 hrs/acre	2,510	1,250	1,512,000	-140.00
Number of machines	50	1,720	1,060	1,328,000	-10.90
	60	1,680	1,060	1,313,000	-14.80
Removal of green fruit	14%	NC	NC	NC	-49.90
	20%	NC	NC	NC	-92.60
Picking cycle	6 days	1,720	1,050	1,295,084	-71.20

1/ Reference results are for a $5,000 machine cost, 16 hours of use per day, 5 day picking cycle, 4 hours to harvest one acre, 40 machines available for use, and 8 percent removal of green fruits which would have been mature for harvest during the following picking.

2/ No change from value given for Reference.

hand picking is judged to be unfeasible. Even tho some criteria used for evaluation are improved, a positive marginal income is considered to be a constraint. In terms of risk, marginal income was negative for three of five years in Southern California and for four of five years in the Central Coast, in addition to being negative for the 5-year average. In other words, the probability of negative marginal income is about .6 to .8.

Reduction of peak labor requirements could be accomplished with the proposed system, however. A maximum of about 2,000 workers would be needed in Southern California instead of nearly 3,000 required for conventional hand picking. Also, labor needs would be stabilized since the maximum number of workers needed would be 1.75 times the average number needed compared to a ratio of 2.2 for hand picking.

7.3 Harvest of selected fruiting stalks (cymes) during peak season

The alternative of picking some fruits by harvesting cymes showed promise. During a limited field test (14 plants) late during the 1972 harvest season, 30 percent of the crop could be picked by cymes with a loss of only 10 percent of the fruits on those cymes. The decision rule used for the test was to harvest any cyme which had two-thirds or more of its fruit mature at the time of picking. Berries on individual cymes tend to mature more uniformly during peak season so for the purpose of the simulation it was assumed that 40 to 60 percent of the fruits could be picked by harvesting cymes with an associated loss of 10 to 25 percent. To estimate the time for picking cymes relative to conventional picking, it was assumed that picking 1 cyme required the same time as picking 2 strawberries. An average of 3 1/3 berries per cyme would give a relative net picking time of 60 percent and 5 berries per cyme would give 45 percent. Cymes picked during the limited test mentioned above averaged 4.5

berries per cyme.

Simulation results are summarized in Tables 28 and 29 for Southern California and the Central Coast, respectively. Parameter values used in the reference run are considered to be realistic based upon experience and limited observations. The results of the sensitivity analysis indicate that marginal income is greatly affected by the relative time for picking by cymes compared to conventional picking and by loss of fruit. Since available information is limited, evaluation of both factors should be carried out as soon as possible to varify economic practicability.

An indication of risk caused by the stochastic process is illustrated in Figure 19. The cumulative distribution functions (CDF) give the probability of marginal income being less than indicated values for the conditions of the reference run.

Risk caused by the stochastic process is illustrated in Figure 19. The cumulative distribution functions (CDF) which are based upon the eight 5-year runs give the probability of annual marginal income being less than indicated values for the conditions of the reference run.

Cyme picking would reduce peak labor requirements from about 3,000 to 2,350 workers in Southern California and from about 4,100 to 3,300 in the Central Coast. The maximum number of workers needed would be about 1.95 times the average number required.

7.4 Production on strawberry walls

Simulation results for the proposed strawberry wall are given in Table 30. Cost of the walls, change in pre-harvest costs associated with using the walls, yield, useful life of the walls, and the relative time for picking can be seen to have very important effects on marginal income. Values used in the simulation were estimated based upon the study

Table 28 Results of Sensitivity Analysis of Picking Cymes (Southern California) to Determine the Effect of Various Factors on Criteria Used to Evaluate Alternatives

Factor under study	Factor value	Criteria			
		Max. number of workers	Avg. number of workers	Annual man-hrs required	Marginal income per acre
Reference run[1/]	--	2,350	1,200	1,337,000	$ 13.10
Machine price	$500	NC[2/]	NC	NC	- 7.23
	$700	NC	NC	NC	-27.50
Number of machines	700	2,410	1,210	1,345,000	15.50
	600	2,480	1,230	1,362,000	16.30
Stemmer price	$ 7,500	NC	NC	NC	13.00
	$10,000	NC	NC	NC	12.90
Stemmer capacity crates/hr	200	2,350	1,200	1,341,000	6.97
	100	2,370	1,210	1,354,000	-11.40
Maximum fruits picked by cyme	40%	2,440	1,230	1,375,000	5.72
	60%	2,370	1,190	1,314,000	17.60
Relative time for picking cymes	30%	2,140	1,140	1,281,000	81.50
	60%	2,590	1,270	1,409,000	-57.20
Loss of fruit	15%	NC	NC	NC	-53.80
	25%	NC	NC	NC	-188.00

1/ Reference results are for using 800 machines costing $300 each; stemmers costing $5,000 each, used 16 hrs per day, and having a capacity of 300 crates per hr; a maximum of 50% of the fruits picked by cyme; a net picking time for cyme picking of 45% of the time for picking individual berries; and a loss of 10% of the crop harvested by cyme picking.

2/ No change from value given for Reference run.

Table 29 Results of Sensitivity Analysis of Picking Cymes (Central Coast) to Determine the Effect of Various Factors on Criteria Used to Evaluate Alternatives.

Factor under study	Factor value	Criteria: Max. number of workers	Avg. number of workers	Annual man-hrs required	Marginal income per acre
Reference run[1/]	--	3,280	1,700	2,574,000	$ 16.70
Machine price	$ 500	NC[2/]	NC	NC	2.18
	$ 700	NC	NC	NC	-12.30
Number of machines	900	3,350	1,710	2,587,000	17.50
	800	3,430	1,720	2,606,000	17.50
Stemmer price	$ 7,500	NC	NC	NC	16.60
	$10,000	NC	NC	NC	16.60
Stemmer capacity crates/hr	200	3,290	1,700	2,580,000	12.00
	100	3,320	1,710	2,597,000	-2.16
Maximum fruits picked by cyme	40%	3,380	1,720	2,616,000	11.20
	60%	3,250	1,700	2,557,000	19.00
Relative time for picking cymes	30%	3,150	1,640	2,492,000	69.80
	60%		1,770	2,670,000	-37.20
Loss of fruit	15%	NC	NC	NC	-32.50
	25%	NC	NC	NC	-131.00

1/ Reference results are for using 1000 machines costing $300 each; stemmers costing $5,000 each, used 16 hrs per day, and having a capacity of 300 crates per hr; a maximum of 50% of the fruits picked by cyme; a net picking time for cyme picking of 45% of the time for picking individual berries; and loss of 10% of the crop harvested by cyme picking.

2/ No change from value given for Reference run.

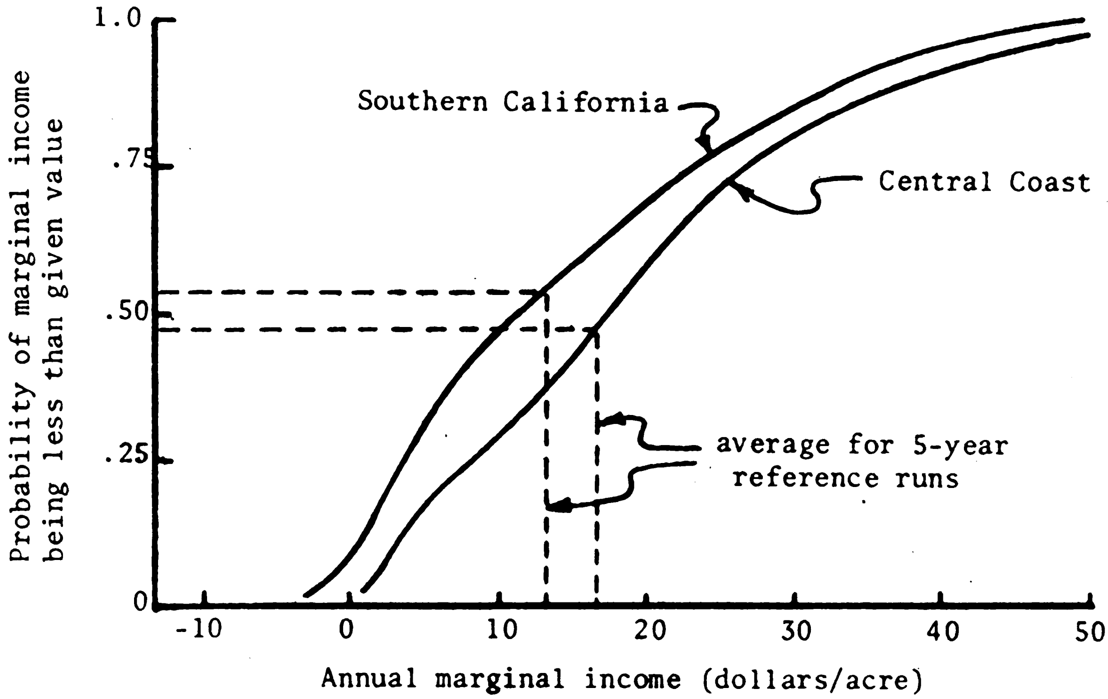


Figure 19 Cumulative Distribution Function of Marginal Income for Picking Selected Cymes During Peak Season

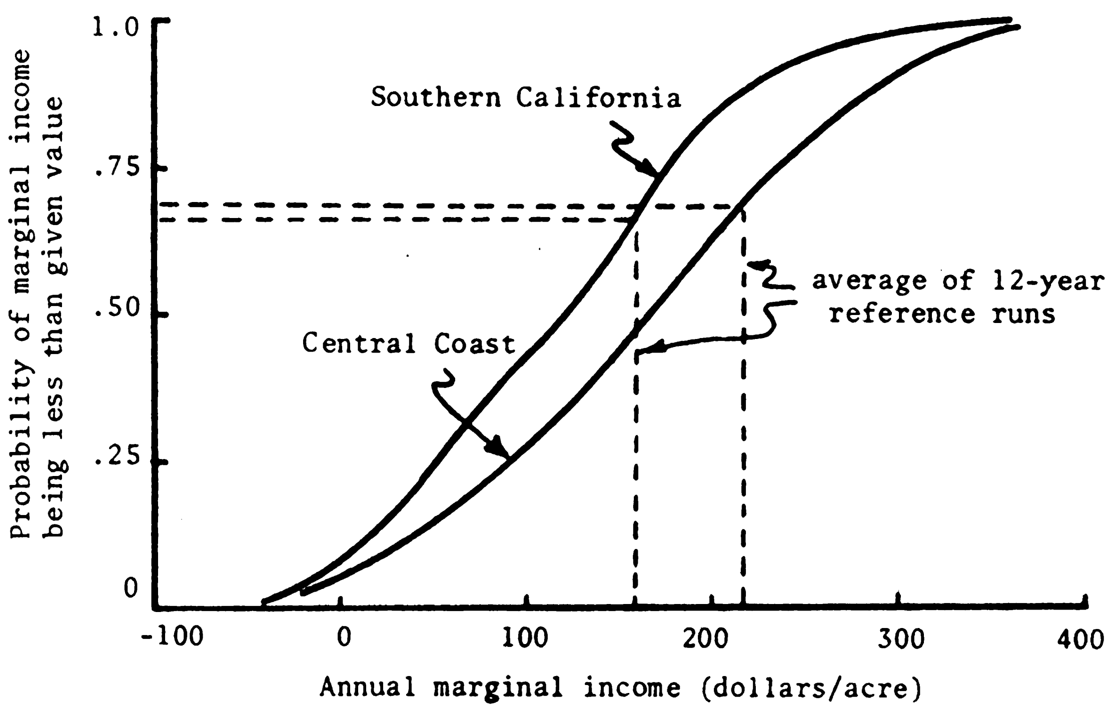


Figure 20 Cumulative Distribution Function of Marginal Income for Strawberry Wall System

Table 30 Results of Sensitivity Analysis of Strawberry Wall System (Southern California) to Determine Effect of Various Factors on Criteria Used to Evaluate Alternatives.

		Criteria			
Factor under study	Factor value	Max. number of workers	Avg. number of workers	Annual man-hrs required	Marginal income per acre
Reference run[1/]	--	1,340	602	735,000	$ 159.00
Cost of walls per acre	$8,750	NC[2/]	NC	NC	-4.87
	$10,000	NC	NC	NC	-169.00
Change in pre-harvest costs per acre	$500 less	NC	NC	NC	499.00
	$500 more	NC	NC	NC	-180.00
Price of picker aids	$400	NC	NC	NC	132.00
	$700	NC	NC	NC	104.00
Increase in production	0	1,170	526	642,000	-257.00
	26%	1,490	668	816,000	549.00
Useful life of system	10 years	NC	NC	NC	-71.20
	8 years	NC	NC	NC	-395.00
Relative time for picking berries	45%	1,740	782	955,000	-47.00
	60%	2,140	963	1,175,000	-253.00

1/ Reference results are for an assumed investment of $7,500 per acre for walls, no change in pre-harvest costs, use of aids which cost $100 per picker, a 13% increase in yield per acre, 12 years system life, and a net picking time of 30% of the time for picking individual berries from conventional beds.

2/ No change from value given for Reference. It should be noted that any possible change in pre-harvest labor is not included.

of Horsfield, 1969, (see Section 5.4). Using the Methods-Time Measurement approach (Maynard, 1948), Horsfield estimated a picking time of 6.3 minutes per crate, or a relative picking time of about 30 percent of conventional hand picking. Horsfield also estimated that walls made from wood would cost about $10,000 per acre. But for this study, it was assumed for the Reference run that use of formed plastic would reduce cost to $7,500 per acre. Pre-harvest costs were varied from $500 per acre less than conventional systems to $500 more. Horsfield estimated a reduction of pre-harvest cost on a per plant basis, but this could give an increased cost per acre due to increased plant population.

Limited tests to date have shown reduced yield on the strawberry wall. However, an improved wall design, which would minimize shading, and an improved watering system, which would maintain good soil moisture, are considered possible. Therefore, yield per acre was assumed to be unchanged or to be increased up to 26 percent.

Results of strawberry wall simulation indicate positive marginal income can be obtained provided a) initial cost is about $7,500 per acre, b) pre-harvest cost are not increased much if any, c) an increase in production of about 10 to 15 percent per acre is accomplished by the increased plant population, d) the system has a useful life of about 12 years or more, and e) picking rate can be about doubled.

Risk associated with the stochastic nature of production is illustrated in Figure 20 for the assumptions used in the Reference run. The probability of negative marginal income is about 6 to 8 percent for both areas. Two points are worthy of note. First, the average marginal income (Table 30) for the 5-year Reference run is such that the probability of having a lower marginal income in any one year is about two-thirds. In contrast,

the probability of having an annual income of less than the average marginal income reported for the cyme picking Reference run was about one-half (Figure 19). Second, the range in marginal income was about 8 times greater for the proposed strawberry wall than for picking selected cymes. The strawberry wall system is very sensitive to production trends and shows great benefit if high yields are achieved.

The maximum number of workers in the Southern California area was reduced from 2,980 for hand picking to 1,340 for the strawberry wall. However, the ratio of maximum number of workers to average number of workers is unchanged from hand picking. Thus, the strawberry wall can be expected to increase the efficiency of production but not to stabilize the need for harvest labor.

7.5 Comparison of hand harvest and proposed harvest systems

Tables 31 and 32 provide a comparison of hand picking with the proposed solutions on the basis of criteria established to evaluate alternatives. From the growers point of view, negative marginal income eliminates the machine harvest system. Criteria values all favor the strawberry wall system. However, both the walls and cyme picking appear to have good potential for the grower. It should be noted that greater uncertainty is associated with the assumed values used in the strawberry wall simulation than with the cyme picking simulation. Figure 21 illustrates the relative merits of each system in terms of reducing the peak labor requirement.

Evaluation from a worker point of view is difficult since the criteria for evaluation are more subjective and harder to define than are grower criteria. Assuming the criterion to be a large amount of long term, stable employment, the values tabulated in Table 31 don't clearly show

Table 31 Comparison of Hand Harvest and Proposed Harvest Systems for Southern California Based Upon Grower Criteria.

Harvest system	Criteria			
	Marginal income[1/] dollars/acre	Risk	Max. number of workers	G[2/]
Hand picking	0	0	2,980	0
Machine harvest and hand picking	-7	.60	1,930	<0
Cyme picking	11	.10	2,350	0.47
Strawberry wall	125	.07	1,340	1.3

1/ Tabulated marginal income is the median value.

2/ $G = \frac{\text{marginal income per acre x number of acres}}{\text{risk x maximum number of workers}}$

Table 32 Comparison of Hand Harvest and Proposed Harvest Systems for Southern California Based Upon Worker Criteria.

Harvest system	Criteria			Standard deviation of number of workers
	Millions of man-hrs per year	$\frac{\text{Thousands of man-hrs/year}}{\text{Max. no. of workers}}$ 1/	W 2/	
Hand picking	1.56	.52	.81	1,000
Machine harvest and hand picking	1.35	.70	.95	674
Cyme picking	1.34	.57	.76	776
Strawberry wall	.73	.55	.41	458

1/ It is noted that 50 weeks of employment at 40 hrs per week would give a value of 2.

2/ $W = \text{Man hrs per year} \times \left(\frac{\text{Man hrs per year}}{\text{Max. number of workers}}\right) \times 10^{-9}$.

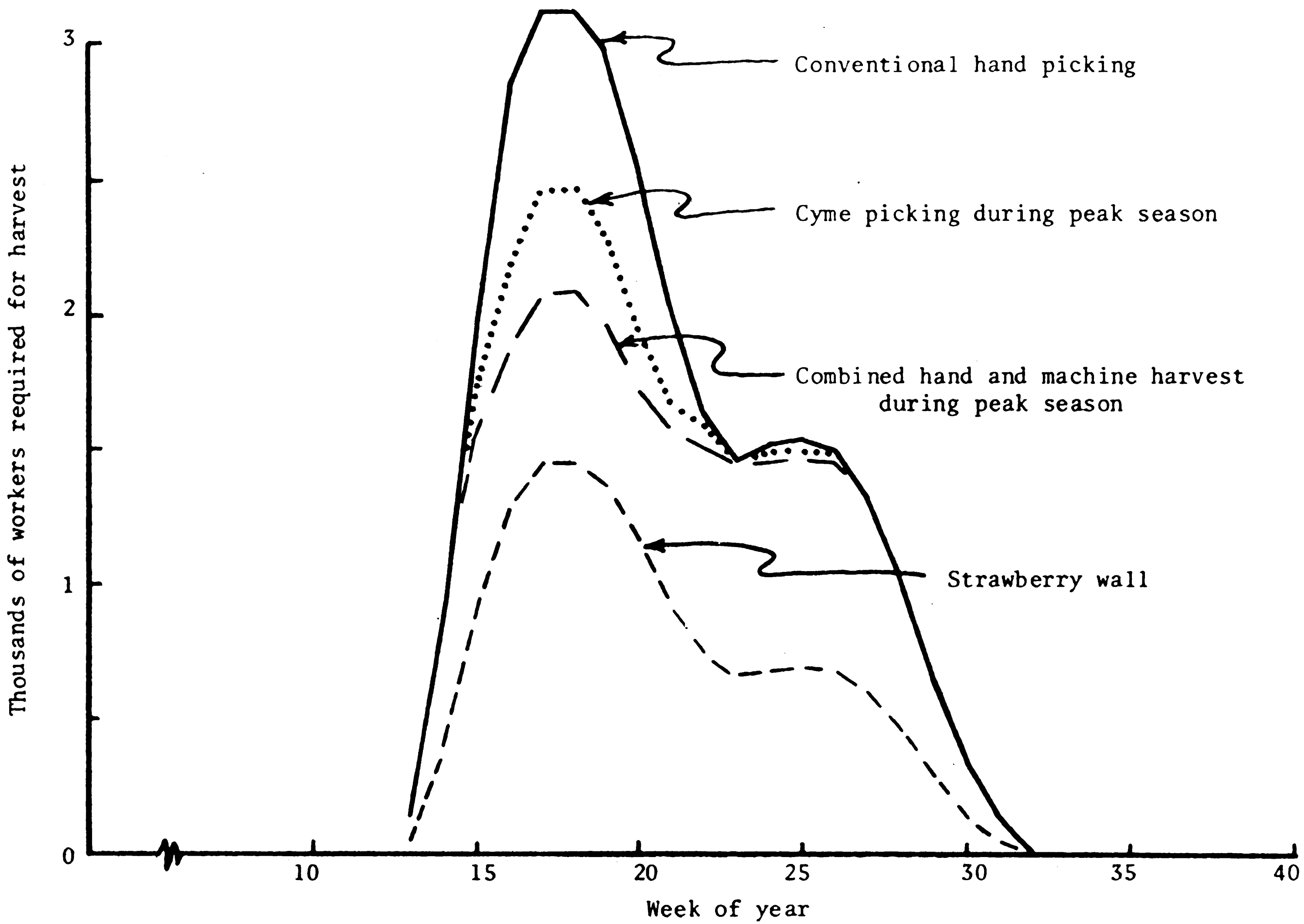


Figure 21 Effect of Simulated Harvest Alternatives on Seasonal Employment in Southern California

any one system to be superior. Figure 21 illustrates the effect of alternatives on seasonal employment.

The proposed machine harvest system would do the best in regards to maintaining employment and at the same time increasing the average work period (man-hrs per year/maximum number of workers), thus the worker criteria W, is high. However, the discussion of the machine harvest system is academic since it was eliminated by constraints on the grower criteria.

Comparison of cyme picking and the strawberry wall favors the former system, primarily due to a substantial reduction in employment associated with the walls (Figure 21). The average work period for both proposed systems is only about 6 to 10 percent greater than for hand picking. However, when the standard deviation of the number of workers is considered, employment with either cyme picking or the strawberry wall can be seen to result in less variance.

8. CONCLUSIONS AND RECOMMENDATIONS

The feasibility study and system simulation demonstrate that development of machine harvest using any current technology is highly unlikely to be practicable for California conditions. Therefore, it is recommended that research effort and funds be directed toward alternative solutions.

Further it is concluded that long range benefits are probable if the strawberry wall is developed. However, cost of the wall and effects of this type production on yield, pre-harvest cost, and picking rate must be established before success can be predicted with confidence.

Short range benefits very likely can be achieved by use of a system whereby selected cymes are picked during peak season to hasten harvest. Confidence in this proposed system should be verified by evaluating the amount of fruit which can be picked by cymes and determining the effect of cyme picking on fruit loss and picking rate. Although the simultaneous use of the strawberry wall and cyme picking was not studied, it would seem to enhance both solutions.

The simulation study indicates that it is possible to consider proposed automated systems as socio-economic systems and develop information relative to the change of worker needs and possible displacement of workers. Table 32 and Figure 21 not only provide data which will aid the engineer in making technical decisions, they also contain data which can aid social scientists in anticipating movement of labor.

9. SUGGESTIONS FOR FURTHER RESEARCH

Continued research on improved systems of strawberry production should include 1) field experiments to better evaluate some of the important system parameters, 2) preliminary design and testing of machine aids to facilitate harvest of fruits by picking cymes, 3) preliminary design and testing of the strawberry wall to better estimate needed inputs and resulting outputs, 4) consideration of using the cyme picking procedure with the strawberry wall system, and 5) continued search for new solutions.

Specific areas which should be researched in relation to the alternative of cyme picking are as follows:

- Determine the net picking time associated with picking cymes and evaluate the effect of yield and time of season.
- Determine the amount of fruit loss associated with picking cymes and evaluate different decision rules regarding when to pick cymes and what percent of the fruit to pick by cymes.
- Evaluate any savings in non picking time which might result from use of a machine aid with cyme picking.
- Explore the feasibility of developing a high capacity stemmer which can provide fruit quality satisfactory for fresh market.
- Explore the possibility of developing a new market to eliminate the need for stemming.

In relation to the strawberry wall, research should be continued as follows:

- Make an in depth estimate of the cost of strawberry walls.
- Research methods of irrigation to accomplish uniform watering (a problem on preliminary tests).
- Determine the net picking time associated with harvesting from the

walls.

- Research means of maintaining good lighting to avoid excessive shading and associated loss of yield
- Evaluate pre-harvest costs including water costs, planting, fertilizing, mulching, weed control, etc.

The simulation study which was conducted should be extended to make a sensitivity analysis of fruit price, useful life of equipment (or facilities), and labor costs for hand harvest. Effects of supply and demand on grower income should be analyzed in terms of the potential loss or gain for growers considering possible changes in total production.

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