Simulation of a Tobacco Mechanical Harvesting and Curing Operation

by

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Introduction

During the last decade there have been numerous simulation developments of various components of crop production systems. Plant growth modeling has been the subject of many investigations (Baker et. al., 1972, Chen et. al., 1969 and Curry, 1971). Insect dynamics has also been simulated by many investigators (Jones et. al., 1975). Models which simulate the machinery interaction in crop production systems have been developed (Morey et. al., 1971). Also there have been a number of total crop production system simulation studies reported. Holtman et.al. (1973) described an approach to simulating the corn production system. Probably the most comprehensive effort to simulate a crop production system is being conducted under Regional Project S-69, Engineering Systems for Cotton Production, which is described by Bowen et. al. (1973).

The flue-cured tobacco production system is one of complexity which is currently on the threshold of major changes to mechanized production systems. The harvesting and curing operations are in the midst of change from predominantly hand labor operations to completely mechanized systems. Many factors will affect the rate at which this change is made. One factor is the rate at which mechanical harvesters and bulk curing structures can be manufactured. A second is the availability, quality and wage rate of manual labor. Tobacco growers who are seriously considering making this jump to mechanization must consider these factors along with ways to most efficiently utilize the resources available if he does make decisions to completely mechanize the harvest and curing operation. If his acreage will under utilize the harvester capacity he might consider leasing additional acreage of tobacco or custom harvesting other farmers' tobacco. He must have the appropriate barn and trailer capacity to keep the harvester operating in the field whenever tobacco is available to be harvested. He could better plan his operation if he understands the interactions among field size, configuration, distance from barns, harvest interval, weather, barn capacity, number of trailers, and harvester operational parameters.

The Model

The simulation model is designed to simulate the harvesting, transportation to barns, and filling and emptying of curing barns. The system being simulation is described by input data of three types: that describing the machinery and equipment involved; that describing the fields, and that describing the curing barns. The model will simulate a single harvester but will accommodate any number of trailers, vehicles to pull the trailers, barns, and fields.

The model is a discrete event simulation and is programmed in the SIMSCRIPT II.5 programming language (Kiviat et. al., 1973). Entities in a SIMSCRIPT model are program elements which represent objects in the system being simulated. The following entities appear in the tobacco harvesting and curing model.

FIELD - represents fields in the modeled system
BARN - curing barns
TRAILER - trailers on the tobacco harvester
TRANSPORT.VEHICLE - vehicles which pull trailers between the barns and fields.

Attributes define the state of a particular entity. Entities and their associated attributes are as follows:

FIELD
- ID - field identification number
- NO.HARVESTS - desired number of harvests
- HARVEST.INTERVAL - desired harvest interval in days
- NO.HARVESTS.COUNTER - a counter which keeps track of the number of times the field has been harvested
- ROWS.PER.LOAD - number of rows required to fill the harvester trailer
- ROW.SPACING - row spacing in inches
- NUMBER.OF.ROWS - number of rows in the field
- HARVEST.DATE - date field is ready for next harvest
- ACREAGE - acres in the field
- LENGTH.OF.ROW - length of rows in feet
- TURN.ROW.CONDITION - a multiplier which adjusts turn time
- DRY.WT.PER.ACRE - average yield in pounds (cured weight) per acre
- AVG.WT.PER.FT.ROW - yield (green weight) per foot of row

BARN
- IDENT - identification number
- CURE.TIME - time tobacco is left in barn during curing (days)
- DATE.EMPTY - date curing will be completed
- GREEN.CAPACITY - pounds of tobacco which can be placed in barn (green weight)
- TOTAL.BARNED - pounds of tobacco actually in barn at some time (green weight)

TRAILER
- TRAILER.LOAD - amount of tobacco in trailer (green weight)

TRANSPORT.VEHICLE
- ID.NO - identification number
- VEHICLE.SPEED - speed of transport vehicle in miles per hour

Sets in SIMSCRIPT make it possible to relate entities to one another. The tobacco harvesting and curing model includes the following sets.

FARM - a set which keeps the fields arranged in the order in which they are to be harvested. The entity FIELD may be a member of FARM which is ranked on the low value of the attribute HARVEST.DATE.

FULL.BARN - a set which keeps the full barns arranged in the order in which they are to be emptied. The entity BARN may be a member of FULL.BARN which is ranked on the low value of the attribute DATE.EMPTY.

EMPTY.BARN - the set of empty barns. The entity BARN may be a member of the set EMPTY.BARN which is ranked first out (FIFO).

BARN.TRAILER.QUEUE - a set of full trailers waiting at the barn for unloading. The entity TRAILER may be a member of BARN.TRAILER.QUEUE which is FIFO.

FIELD.TRAILER.QUEUE - a set of transport vehicles with trailer attached waiting for a harvester in the field. The entity TRANSPORT.VEHICLE may be a member of FIELD.TRAILER.QUEUE which is FIFO.

TRANSPORT.VEHICLE.WAITING - a set of transport vehicles waiting at the barns for an empty trailer to return to the field. The entity TRANSPORT.VEHICLE may be a member of TRANSPORT.VEHICLE.WAITING which is FIFO.

Since the model is designed to simulate the operation of a single tobacco harvester it is not necessary to identify the harvester as an entity. The harvester's attributes are program variables and include:

SPEED.AVG. - average speed of harvester in miles per hour

LOAD.CAPACITY - maximum capacity of the harvesters trailer in pounds (green weight)

AVG.TURN.TIME - average time to turn the harvester around at the end of a row assuming ideal conditions (TURN.ROW.CONDITION=1) (minutes)

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AVG.UNLOAD.TIME - average time to remove a full trailer from the harvester and replace with an empty trailer (minutes)

MEAN.TIME.BETWEEN.FAILURES - average time between successive harvester breakdowns (hours)

AVERAGE.DURATION.OF.FAILURES - average time the harvester is down given that there is a failure (minutes)

The SIMSCRIPT II.5 programming language simulates the interaction of entities at discrete points in time. The discrete points in time are represented as events which usually are scheduled to occur at the beginning and/or end of an activity. Events are scheduled to occur at some clock or calendar time and as the simulation proceeds from one event to the next, passage of time is simulated. Relationships among events and routines are pictorially depicted in Figure 1. The tobacco harvesting and curing model contains the following events:

WEATHER.REPORT - an event which is scheduled each morning at a prescribed time (e.g. 8 am)(Figure 2). Weather, barn and field status are checked at this time and harvesting is scheduled if each condition is met. If harvesting is scheduled this event also determines which field should be harvested and into which barn the tobacco will be placed for curing. The events DAILY.REPORT for that same day and WEATHER.REPORT for the next day are scheduled.

HARVEST.ROW - simulates the activities associated with harvesting a row of tobacco (Figure 3). It updates the row counter and determines harvest time, turn time, pounds of tobacco harvested per row and breakdown time (if applicable) for the row. If it is time to unload the harvester, the event COMBINE.ARRIVAL (Figure 4) is scheduled, otherwise the routine HARVEST.STATS (Figure 5) is called. The routine HARVEST.STATS schedules the event COMBINE.ARRIVAL if harvest is completed for the field.

COMBINE.ARRIVAL - simulates the activities associated with the arrival of the harvester at the end of the row with a trailer full of tobacco. If there is a transport vehicle waiting the full trailer is replaced by an empty trailer and taken to the barn. Otherwise, the harvester awaits a transporter. When the field unloading activity is completed this event schedules the event TRAILER.ARRIVAL.BARN (Figure 6) in the time required to deliver the trailer to the barn. The COMBINE.ARRIVAL event also checks to see whether the barn which is being filled is full, if so, calculates DATE.EMPTY and removes the next barn from EMPTY.BARN. If there is no barn available, the harvesting operation ceases.

TRAILER.ARRIVAL.BARN - simulates the arrival of a transporter with a full trailer at the barn. If there is a queue of full trailers waiting to be unloaded the trailer is filed in the queue BARN.TRAILER.QUEUE, otherwise it is unloaded and the event END.OF.TRAILER.UNLOADING (Figure 7) is scheduled. A check is made to see if there are any empty trailers available. If so, the transporter and empty trailer are dispatched to the field by scheduling the event TRAILER.ARRIVAL.FIELD (Figure 8), otherwise the transporter is filed in the set TRANSPORT.VEHICLE.WAITING.

END.OF.TRAILER.UNLOADING - represents the completion of the trailer unloading activity at the barn. If there is a full trailer waiting in set FULL.TRAILER.QUEUE, the event END.OF.TRAILER.UNLOADING is scheduled for that trailer. When a trailer is unloaded a check is made to see if there are any transporters in the set TRANSPORT.VEHICLE.WAITING. If so, a transporter is removed from the set and dispatched to the field with the empty trailer and the event TRAILER.ARRIVAL.FIELD is scheduled. If not, the number of empty trailers at the barns is incremented by one.

TRAILER.ARRIVAL.FIELD - simulates the arrival of a transport vehicle and an empty trailer in the field. If there is a harvester waiting in the field to be unloaded it is unloaded and the event TRAILER.ARRIVAL.BARN is scheduled in a time equal to the unload time plus transport time. Also HARVEST.STATS is called to start another harvest operation for a new row in field. Otherwise the transporter and empty trailer are filed in the set FIELD.TRAILER.QUEUE.

UNLOAD.BARN - simulates barn unloading if any barns have completed the cure (Figure 9). This event is scheduled to occur early each morning.

DAILY.REPORT - scheduled to occur each day after all work has been completed. Prints out daily statistics on harvester, barns, fields, and trailers.

WEEKLY.REPORT - similar to DAILY.REPORT except that it is scheduled to occur once each week.

END.OF.SIMULATION - scheduled from the event UNLOAD.BARN after all barns have been emptied. Prints seasonal data and stops the simulation.

In addition to these ten events the SIMSCRIPT program contains two routines, a main program, and the preamble. The preamble identifies entities, attributes, sets, events and declares modes of variables and arrays. The main program reads some input data, calls the initialization routine, puts some events on the calendar and passing control of the program to the timing mechanism. The two routines are as follows:

INITIALIZATION - reads input data -- variables and attributes --, calculates values of other attributes and variables, and files some entities in sets.

HARVEST.STATS - called from the event HARVEST.ROW. A check is made to see if the field is finished. If so, the event COMBINE.ARRIVAL is scheduled and moves the harvester to the new field if appropriate, otherwise the event HARVEST.ROW is scheduled to harvest another row. When there is no new field ready for harvest, the harvester is idle for the rest of the day.

Example Application

This example application of the tobacco harvesting-handling-curing simulator is based on field data obtained from a farm operation in North Carolina in 1973. The farm contained 30.34 acres of tobacco in nine fields as shown in Table 1. The average yield per acre was 3300 lbs of cured tobacco. The desired number of harvests for all fields was four and the desired interval between harvests was 10 days. Desired date of the first harvest is given in Table 1.

Pertinent data on the mechanical harvester are given in Table 2. Three trailers and one transport vehicle, a 1/2 ton farm truck, were available to the operation. Average speed of the truck from the fields to the curing barns was 15 mph. Nine curing barns were available. Each had a capacity of 8640 lbs of green tobacco and a curing time of seven days. Distances between the fields and curing barns are shown in Table 1.

The model was used to first simulate the harvesting-handling-curing system for the season using data described in the preceeding paragraphs as a base. Four additional runs were made to study the performance of the system as related to barn capacity and acreage of tobacco.

Table 1. Input data describing fields on farm in example application.

Field No.	Size (acres)	Row Length (ft)	Desired Date of First Harvest (Julian Date)	Distance From Field to Barns (miles)
1	1.57	162	190	0.2
2	2.01	440	191	1.6
3	1.42	540	192	1.7
4	4.51	675	192	0.8
5	1.03	840	193	1.0
6	3.84	780	194	2.4
7	5.42	570	198	2.6
8	7.09	720	200	2.2
9	3.45	530	201	0.7

Results and Discussion

Two measures of performance of the harvesting-curing-handling system are utilization of resources available and actual harvest schedule vs. desired harvest schedule. Of particular interest are utilization of the harvester and curing barns. The desired harvest schedule is shown in Figures 10-13. It is based on the desired day of first harvest, number of harvests and interval between harvests.

When the actual harvest of a field falls behind the desired harvest date, adjusted harvest dates for the remaining harvests are established.

The desired harvest scheduled, adjusted harvest schedule, and simulated harvest schedule for each of the nine fields, using the base data, are shown in Figure 10. The fourth simulated harvest of field nine was completed four days later than the desired date, but on the adjusted harvest date. The harvester was idle a part or all of 39 of the 40 possible harvest days. Barn capacity became limiting on eight days. Figure 11 presents the harvest schedules resulting when the number of curing barns is reduced to seven. Barn capacity became limiting on 21 of the 40 harvest days and simulated date of harvest for field nine was 7 days later than the desired date. Results indicate that for the base acreage of 30:34 acres, it would be undesirable to reduce number of curing barns to seven.

From the results shown in Figures 10 and 11 it is apparent that the harvester capacity is being under utilized. Thus, an additional 10 acres of tobacco was added by increasing the size of fields 1, 2, 3, and 5 by two acres and fields 4 and 6 by two acres. The simulated harvest schedule with 9 curing barns is shown in Figure 12. Barn capacity was limiting on 22 of 42 possible harvesting days. Increasing the number of barns to 11 resulted in harvest schedules as shown in Figure 13, and 8 days of limited barn capacity. Simulated harvest date for the final harvest of field nine was 8 days later than the desired date when 9 barns were available and 4 days late when 11 barns were available.

Utilization of the harvester and curing barns for the four conditions simulated are shown in Table 3.

Summary

A discrete event model was developed to simulate flue-cured tobacco harvesting handling and curing. Based on inputs describing the fields, harvester, curing barns, trailers and transporters the models simulate the harvesting operation, movement of harvested tobacco from the fields to the curing barns and filling and emptying the curing barns. The model is used to evaluate harvest scheduling, utilization of facilities and equipment, and matching components of the harvesting-handling-curing systems for efficiency.

Table 2. Input data describing mechanical harvester in example application.

Average Row Speed	3.0 miles/hour
Average Turn Time	0.58 minutes
Average Unload Time	2.6 minutes
Mean Time Between Breakdowns	20 hours
Average Downtime	1.0 hours
Capacity of Trailers	900 lbs of green tobacco

Table 3. Summary statistic showing harvester utilization for four conditions simulated.

	30.34 Acres 7 Barns	30.34 Acres 9 Barns	40.34 Acres 9 Barns	40.34 Acres 11 Barns
No. of Potential Harvest Hours	378	360	387	360
No. of Simulated Harvest Hours	146	144	182	181
No. of Simulated Hours Harvester was Idle				
All Barns Filled	111	49	95	36
No. Fields Ready For Harvest	96	143	83	116
No. Empty Trailer in Field	25	24	27	27
Number of Unused Barn-Days	64	134	97	137

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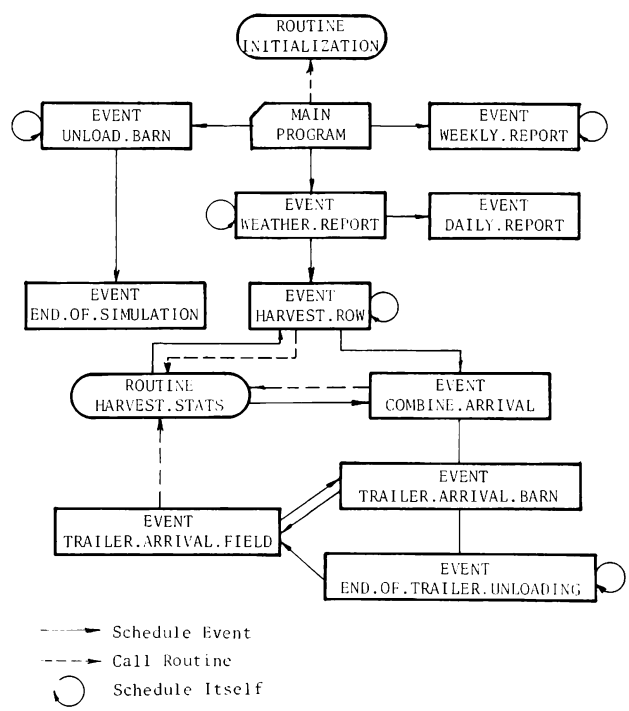

Figure 1 - System flow chart for tobacco harvesting and curing model.

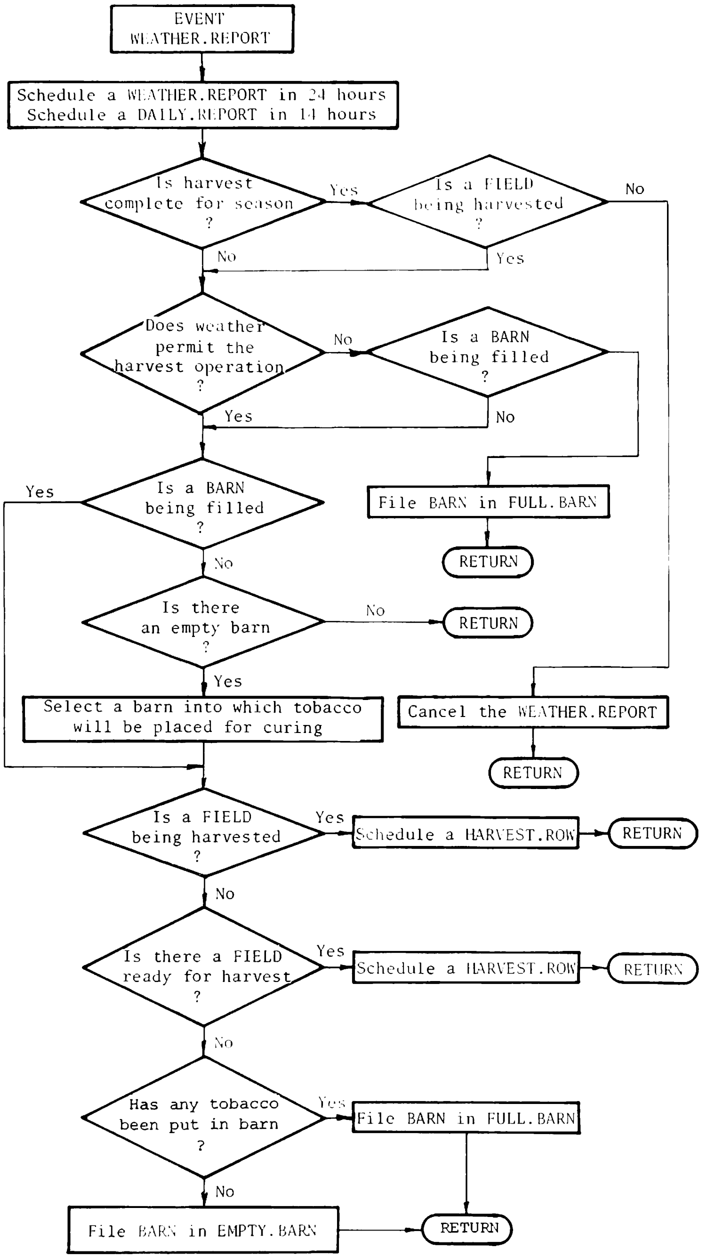

Figure 2 - Flow chart for the event WEATHER.REPORT.

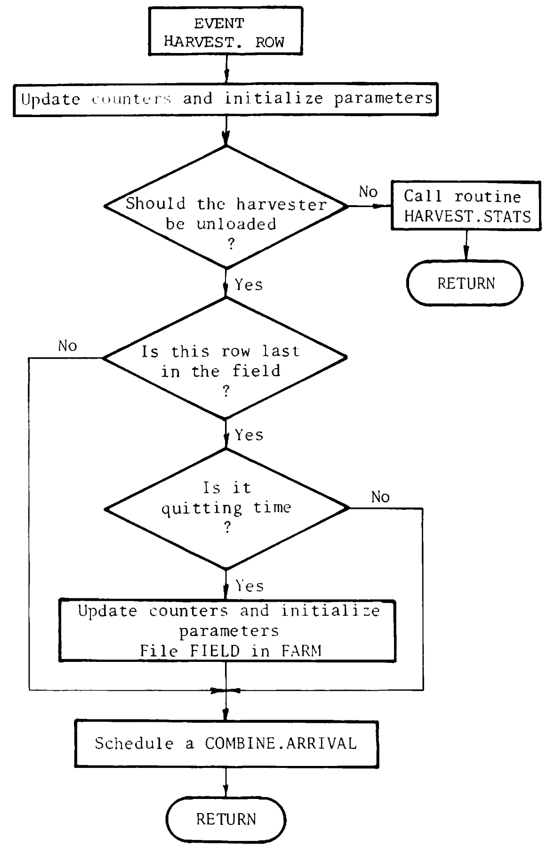

Figure 3 - Flow chart for the event HARVEST.ROW.

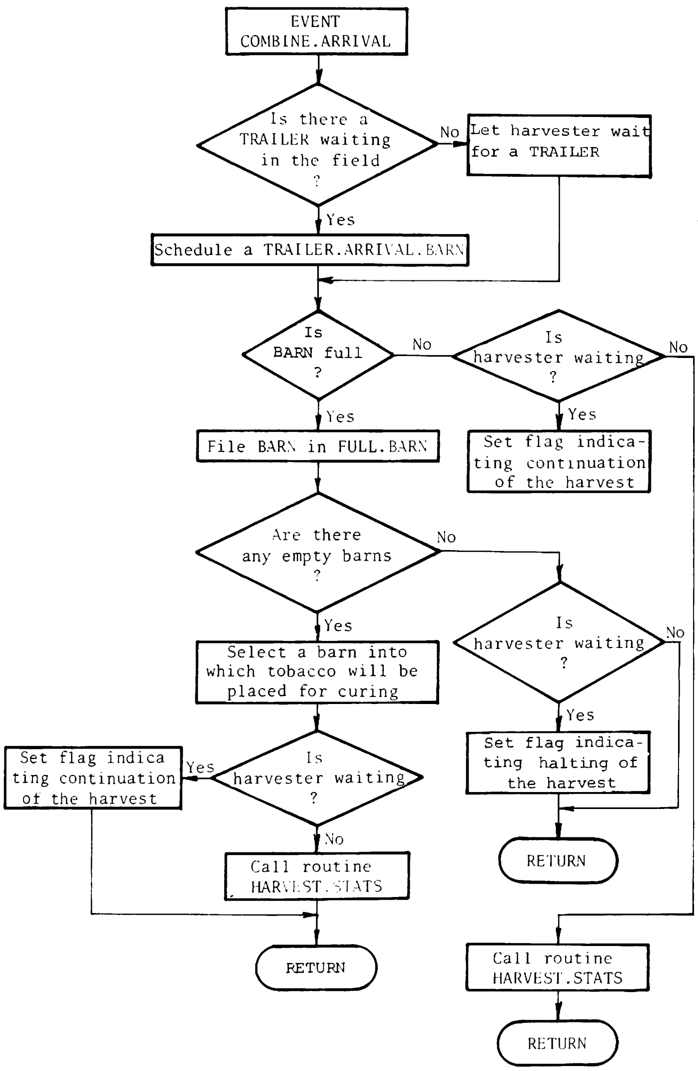

Figure 4 - Flow chart for the event COMBINE.ARRIVAL.

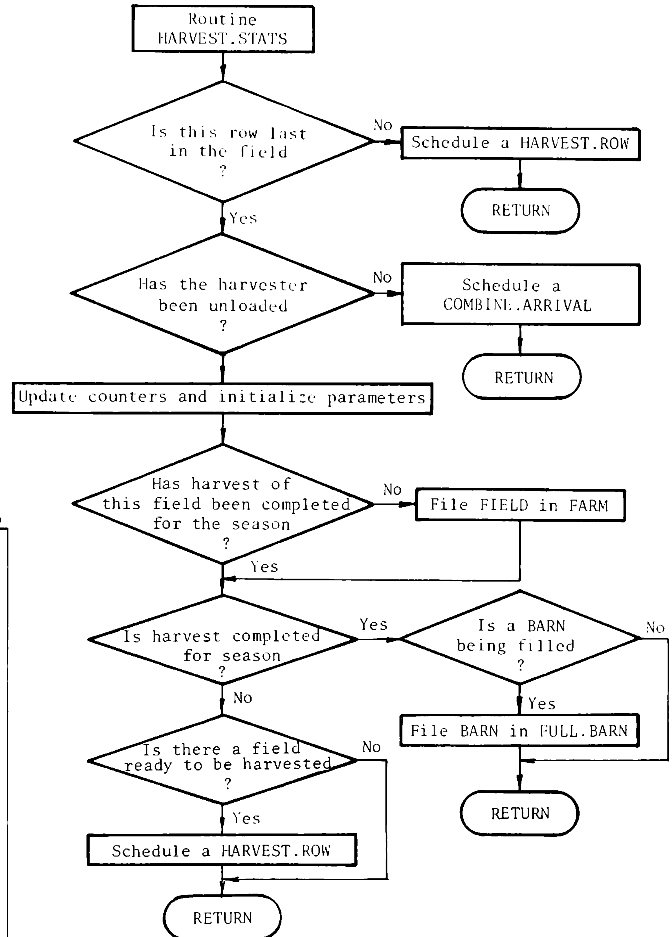

Figure 5 - Flow chart for the routine HARVEST.STATS

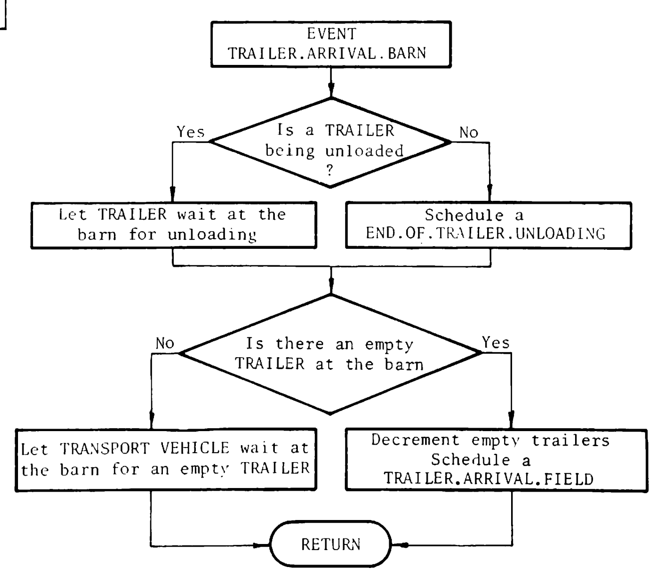

Figure 6 - Flow chart for the event TRAILER.ARRIVAL. BARN.

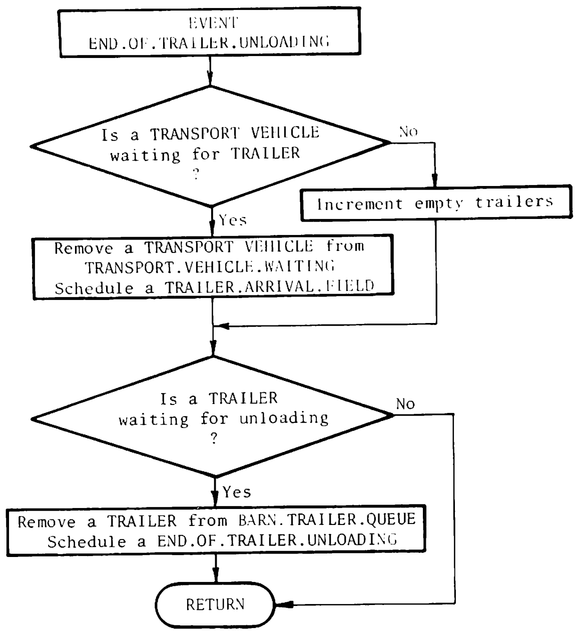

Figure 7 - Flow chart for the event END.OF.TRAILER.
UNLOADING.

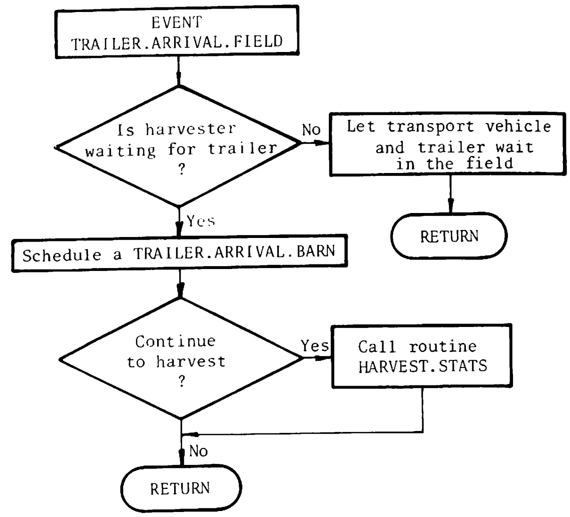

Figure 8 - Flow chart for the event TRAILER.ARRIVAL.
FIELD.

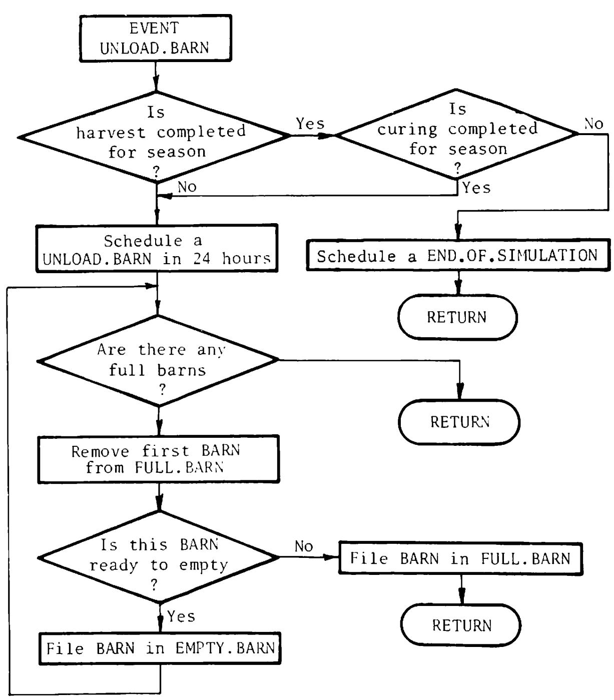

Figure 9 - Flow chart for the event UNLOAD.BARN.

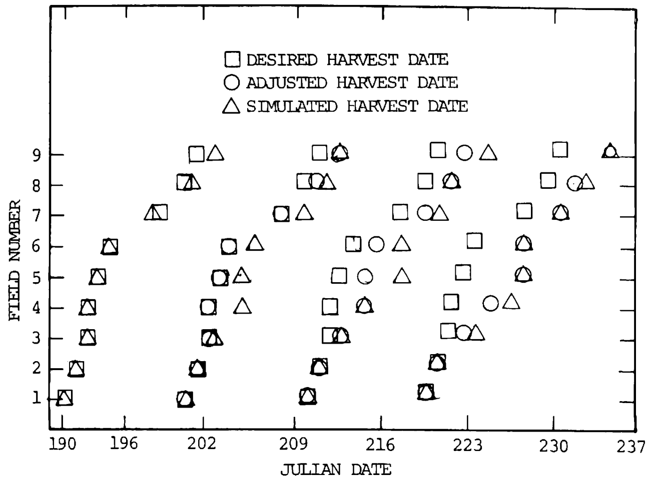

Fig. 10. Desired, adjusted and simulated harvest schedule for 9 fields (30.34 acres) and 9 barns system.

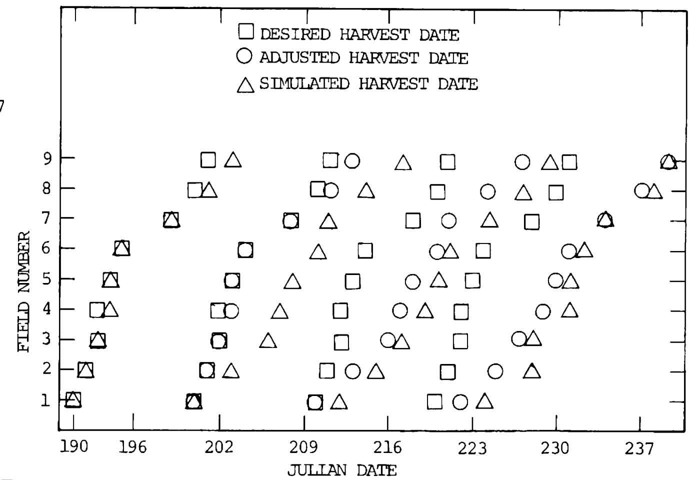

Fig. 12. Desired, adjusted and simulated harvest schedule for 9 fields (40.34 acres) and 9 barns system.

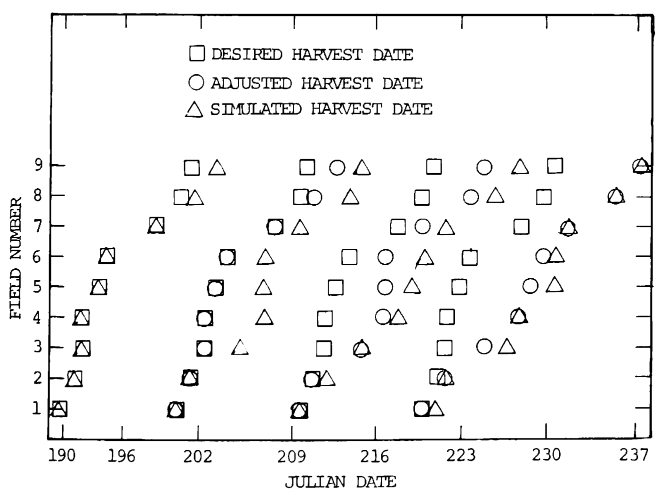

Fig. 11. Desired, adjusted and simulated harvest schedule for 9 fields (30.34 acres) and 7 barns system.

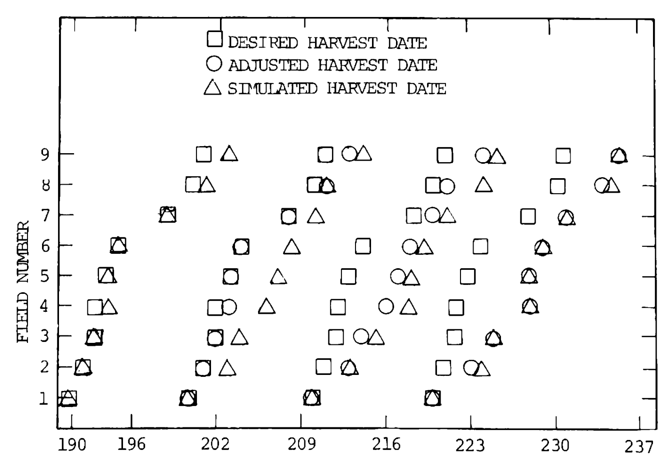

Fig. 13. Desired, adjusted and simulated harvest schedule for 9 fields (40.34 acres) and 11 barns system.