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A Program and Documentation for Simulation of a Rubber-Tired Feller/Buncher

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Presents a computer model written in GPSS (General Purpose Simulation System) designed to simulate and study the productivity and in-woods operation of a rubber-tired feller/buncher.

KEY WORDS: GPSS (General Purpose Simulation System), computer, harvesting, productivity, modeling.

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A PROGRAM AND DOCUMENTATION FOR SIMULATION OF A RUBBER-TIRED FELLER – BUNCHER

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Computer modeling of forest harvesting systems has many applications, each requiring a different approach to simulation. Simulations range from technical descriptions of the machine components for equipment design to overviews of large systems where the model estimates the changes in productivity caused by major system changes. The Forestry Sciences Laboratory personnel at Houghton, Michigan, have been developing harvesting simulators as a forest engineering research tool for several years (Bradley *et al.* 1976; Bradley and Winsauer 1976, 1978; USDA Forest Service 1978; Winsauer 1980).

The purpose of this paper is to document a computer model for a rubber-tired, frame-steered feller/buncher (fig. 1). The model was developed to provide a detailed study of the machine's operation in the woods during felling and bunching. It allows the user to determine cost and productivity under various stand and harvest conditions, ways to increase machine efficiency, or to study the effect of changing harvest patterns on cost and productivity Complete variable lists, program listings, and flow charts are included in Appendices A, B, and C.

THE EQUIPMENT STUDIED

The feller/buncher simulated is a rubber-tired frame-steered chassis with a shear mounted on the front. The shear accumulator can hold one or more trees, but the machine must drive up to each tree to fell it.

MODEL OBJECTIVES

The primary objective of this model is to allow a detailed study of the productivity and operation of the feller/buncher in the woods. For input, the model requires data on the machine's operating characteristics, the stand, and the type of harvest to be carried out.

After simulating the harvest of a plot, the model reports productivity figures such as: trees, tons and volume per hour and per load, total cycles, tree per cycle, distance traveled, and skid bunches completed.

Additional output gives details of the woods operation, distributions of cycle times, distances, number of trees per bunch, size of skidder bunches, frequency and length of delays, etc.

SIMULATION LANGUAGE—GPSS

The simulation is written in General Purpose Simulation Language (GPSS) with output subroutines written in FORTRAN. GPSS is a discrete event simulation language developed by IBM (Schriber 1974). The user constructs a block diagram by arranging the discrete events of a system in their logical structure. The block diagram is made up from a group of specific GPSS block types. These blocks then become the GPSS program. A basic understanding of the GPSS language allows the user to accurately interpret or modify the simulation.

Figure 1.—*Typical rubber-tired type feller/buncher.*

Most versions of GPSS have a standard output format that contains allthe data in a very concise form. The FORTRAN subroutines are used to present the output values of most interest in an organized, labeled form.

MODEL ASSUMPTIONS

The basic time unit used in the model is a centiminute; i.e., 1/100 of a minute. The feller works one shift a day for the number of days chosen by the user. All volume measures are in 1/100 cubic foot.

It is assumed that the feller/buncher operates in an area far enough in advance of the skidder to minimize interactions between machines. To simulate a hot logging operation, this model can be combined with a complete skidding-chipping or skidding-loader model. Another alternative would be to add a "black box" skidder segment, a simplified segment, used to create the machine interactions without providing a detailed study of the skidder operation.

Since an efficient skidder load usually contains more trees than the shear can hold, the feller/buncher may shear and drop several loads at one location to create the skidder bunch.

The following assumptions are made about the feller/buncher's behavior:

1. A feller/buncher cycle is defined as starting after a load is dropped and ending when the next load is dropped.
2. The machine has an accumulating shear. (The model can easily be changed to single head shear by limiting the accumulator load to one.).
3. The feller/buncher must move up to each tree to shear it. It travels back and forth across a relatively narrow strip of forest, cutting trees marked for cutting as it encounters them, working its way along the trip until the far end of the plot is reached. It then moves to the next strip and repeats the process (fig. 2).
4. The feller will cut and accumulate multiple trees before dropping them. It will drop the accumulator head load when the accumulator head is full or if the next tree to cut is too far away.
5. When the feller must drop the trees held in the accumulator head, it will carry the load to the partial bunch and drop the trees there. If no partial skidder bunch has been started or if the partial bunch is judged to be too far away, it will drop them at the location of the last tree cut.

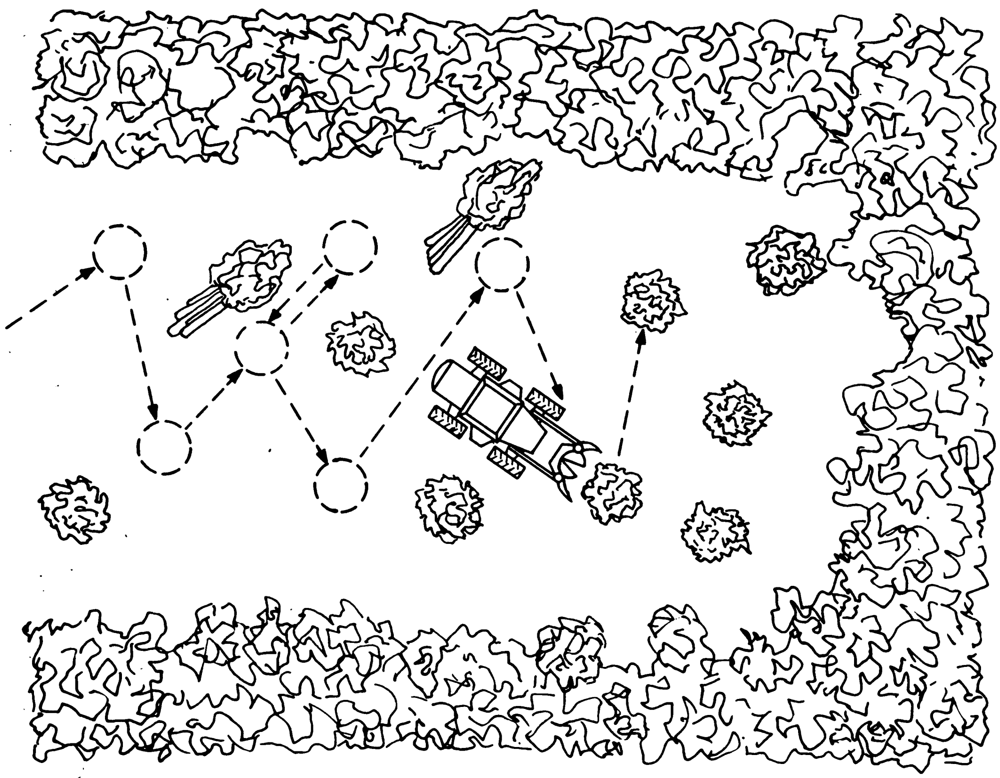

Figure 2.—*Feller/buncher travel pattern.*

6. The feller/buncher operator can quit for the day or stop for a break only after dropping the trees in the accumulator head.
7. Mechanical and nonmechanical delays for the feller are also incorporated into the model. For ease of programming, they are assumed to occur in a cycle after the feller/buncher drops the current load of trees.

MODEL DESCRIPTION

The model consists of two GPSS segments:
1. TIMER SEGMENT
2. FELLER/BUNCHER SEGMENT

and two FORTRAN subroutines for formatted (easily read) output.

The TIMER SEGMENT (fig. 3) controls the daily schedule, keeps track of the days worked, and sends information to the subroutines to produce the formatted output. The TIMER signals the start of the day, the rest breaks and lunch (two 15-minute breaks a day and ½-hour lunch are assumed), and the end of the workday. The TIMER then completes the 24-hour day and produces an output report of the previous day's operation and production. Output is produced at the end of 24 hours, not at the end of the shift, to include the time needed for the feller to complete the bunch being worked on before quitting for the day. If the required number of days have been simulated, the model shuts off. Otherwise, the start of another workday is signaled, and the process continues.

The FELLER/BUNCHER SEGMENT (fig. 4) models a rubber-tired, frame-steered feller/buncher with an accumulating head shear mounted on the front. The machine must move up to each tree to cut it.

It moves through the woods along a strip but travels back and forth within the strip in order to reach the trees to be cut. The feller/buncher attempts to create bunches large enough to be skidded economically.

DATA NEEDS

GPSS accepts machine and stand data in several forms (table 1). For additional information on data types and card formats, see a GPSS Programming Manual (Schriber 1974).

Most of the data required in the main program are expected in the form of GPSS VARIABLES. These VARIABLES are then defined at the end of the deck in terms of the available machine and stand data.

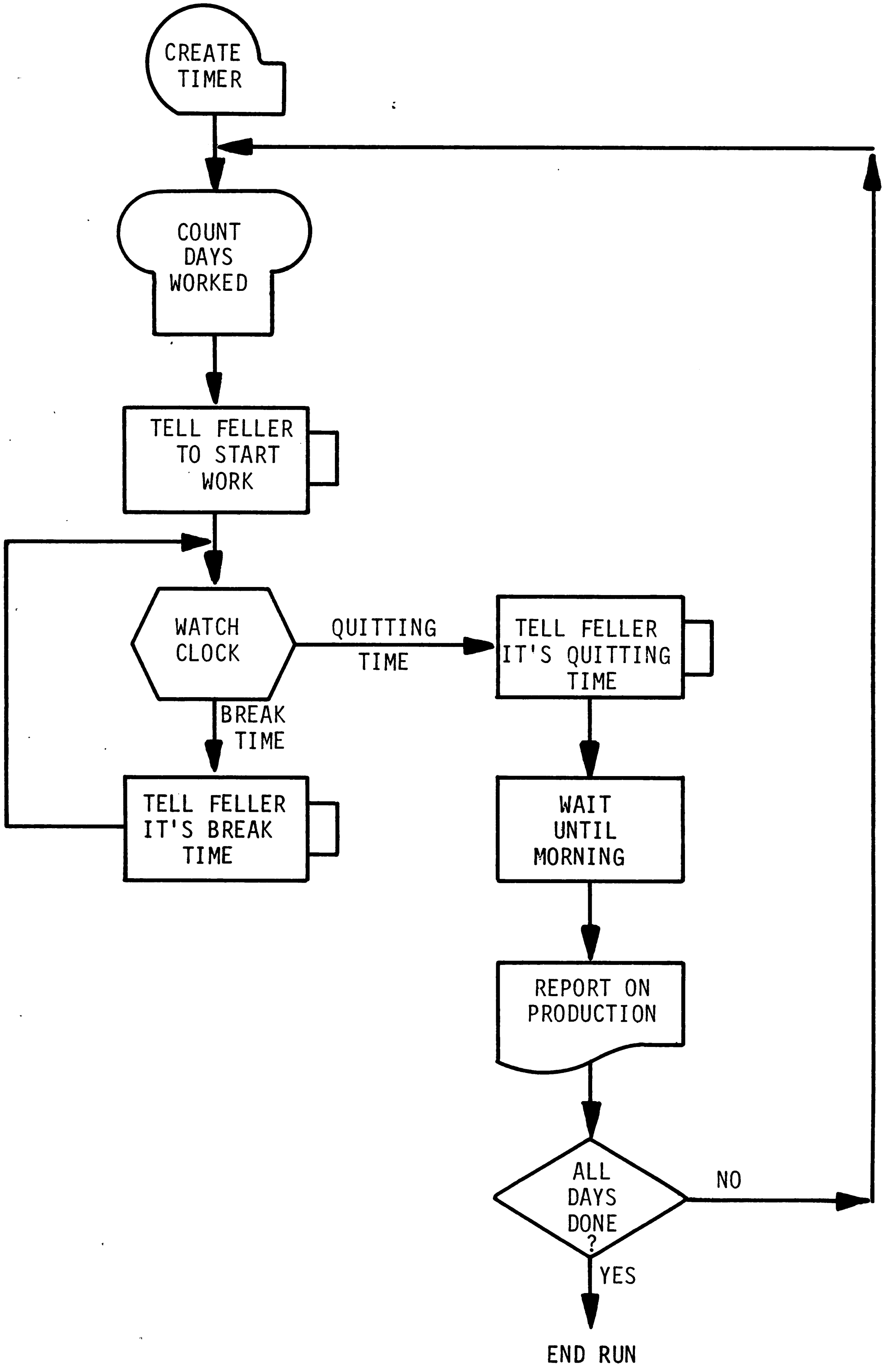

Figure 3.—*Timer segment—overview.*

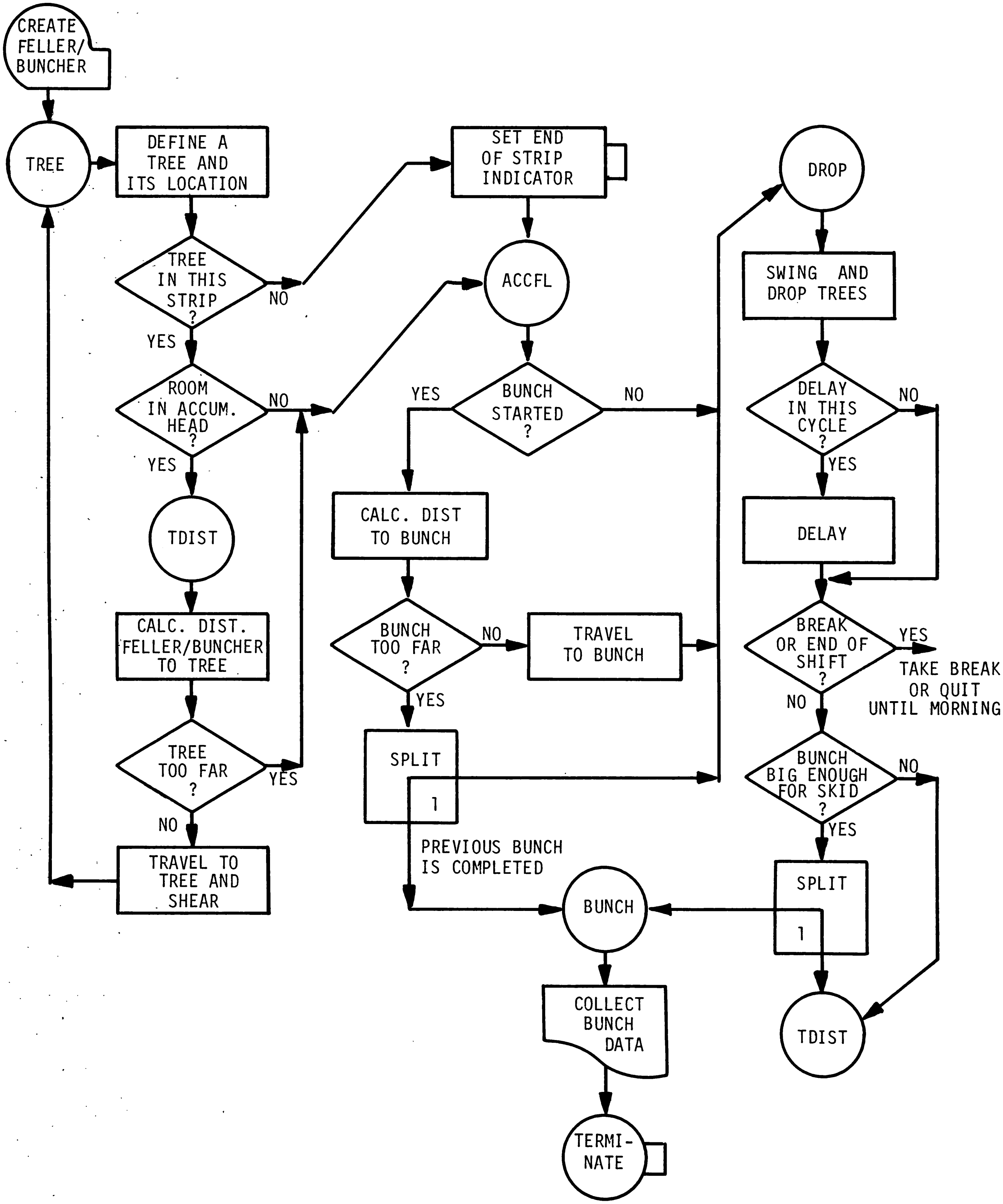

Figure 4.—*Feller/buncher segment—overview.*

Table 1.—*PSS data input forms*

Input data type	Input form in GPSS	Example
Simple averages or constants	Initialized SAVEVALUES	Ave d.b.h. = inches
Range of values	Initialized SAVEVALUES for mean and ½ width of interval	Shear Time = 10 to 14 c min = 12 ± 2 c min
Equations	VARIABLES	Volume = .13 d.b.h.^{2} − .28
Frequency distributions	FUNCTIONS	D.B.h. (in.) 4 | 5 | 6 | 7 | 8; Percent trees 23 | 25 | 30 | 15 | 5
Mean and variance for a standard distribution such as normal, poisson exponential, etc.	SAVEVALUES and FUNCTIONS for the distribution	Wait time is normally distributed with mean = 10 variance = 9

This allows the user flexibility in data form while avoiding card shuffling in the main program For example, changing a shear time from a constant (GPSS SAVEVALUE) to a frequency distribution (GPSS FUNCTION) is accomplished by simply redefining the shear time VARIABLE and supplying the appropriate cards .

The input data cards follow the VARIABLE definitions and are supplied as FUNCTIONS or SAVEVALUES depending upon the VARIABLE definition. An exception to this convention is the use of GPSS SAVEVALUES (constants) merely for summary purposes (average stand d.b.h., average tree height, etc.).

Four types of data describing the equipment and harvesting operation must be supplied.

1. Stand data (table 2).
2. Machine data dependent upon stand conditions (table 3).
3. Machine data (independent of stand) (table 4).
4. Simulation run control (table 5).

The output example presented in this paper uses the information in tables 2 through 5 as input. These data were gathered from time studies carried out during Forest Service case studies. The data in the tables are empirical, so they represent the operating characteristics of this machine under the stand conditions found during the time studies. Different harvest conditions may require new time study data.

SIMULATION OUTPUT

The simulation run produces two pages of formatted output for each day of the run (figs. 5 and 6). These present a summary of the stand data and a cumulative productivity report.

Additional, standard GPSS output is produced at the end of the run by the GPSS processor and supplies complete run details (fig. 7).

The first page of the standard output presents a simulation "map" listing all the blocks in the model and the number of transactions that have moved through each block. This is of primary value while debugging the model. The listing of the QUEUE sta-

Table 2.—*Stand data*

Data required	Case study	Form required by program	Name
Average stand diameter	5.1 in d.b.h.	SAVEVALUE	X$AVDBH
Average stand volume	2,842 cu ft./acre	SAVEVALUE	X$AVVOL
Average tree height	60 ft	SAVEVALUE	X$AVHGT
Average trees/acre	550 trees/acre (all sizes)	SAVEVALUE	X$TRPAC
Strip length	660 ft	SAVEVALUE	X$STPLN
Distance between strips	32 ft	SAVEVALUE	X$MVSTP
Density of wood	55 lb/cu ft	SAVEVALUE	X$LBCFT
Hours in daily work shift	8 hours	SAVEVALUE	X$WKDAY
Actual tree diameter	Diameter distribution	SAVEVALUE	V$TDIAD
Volume of trees	Volume of trees (cu ft)	VARIABLE	V$TVOL

Diameter distribution:

d.b.h. (in.)	2	4	6	8	10	12	14	16	18	20
Percent trees	25.4	22.5	30.4	8.6	6.3	3.2	2.0	1.1	.4	.2

Volume = −0.283 + 0.0031 (d.b.h.^{2}) tree height
= −0.283 + 0.186 (d.b.h.^{2})

Table 3.—*Machine data dependent on stand conditions*

Date required	Case study	Form required by program	Name
Expected X coordinate of the next tree to be cut	X coordinate equally likely to fall anywhere in the strip X coordinate = strip width X (Rand #1) + 1	VARIABLE	V$XCORD
Expected Y coordinate of the next tree to be cut[1]	Distribution of the difference in feet (next tree's Y coordinate—current tree's Y coordinate)	VARIABLE	V$YCORD
Maximum distance feller will travel to add another tree to accumulator head	8 feet	SAVEVALUE	X$ADLIM
Maximum distance feller will travel to add additional trees to a partial bunch	45 feet	SAVEVALUE	X$BDLIM

Y DIF	0	2	4	6	8	10	12	14	16	18
Percent trees	18	30	16	12	8	4	4	3	3	2

[1]The empirical distribution of the expected location for the next tree to be cut could be replaced with an analytic function (Bradley, Dennis P. An analytical procedure to locate trees for simulated tree harvest, (manuscript in process).

Table 4.—*Machine data*

Data required	Case study	Form required by program	Name
Travel time (based on distance)	Travel speed Mean = 150 ft/min St. dev. = 50 ft/min	VARIABLE	V$FBTRAV
Shear time per tree	Shear time Mean = 25 centi-min St. dev. = 12 centi-min	VARIABLE	V$FBSHR
Drop time per load	Drop time Mean = 15 centi-min St. dev. = 9 centi-min	VARIABLE	V$FBDRP
Maximum size of skidder bunch the feller creates (sum total of diameters)	Bunch diameter limit 45 inches	VARIABLE	V$BUNLM
Gal/hr fuel used	4.7 gal/hr	SAVEVALUE	X$FBGPH
Length of nonmechanical delay per cycle (including cycles with zero delay)	Distribution of nonmechanical delays (min)	VARIABLE	V$NMDLY
Length of mechanical delay per cycle (including cycles with zero delay)	Distribution of mechanical delay (min)	VARIABLE	V$MCDLY

LENGTH OF DELAY	0	0-1	1-2	2-5	5-10	10-20	20-50
Percent of cycles	97.3	.9	.5	.5	.4	.3	.1

LENGTH OF DELAY	0	0-5	5-10	10-50
Percent of cycles	99.4	.2	.2	.2

Table 5.—*Simulation run control*

Data required	Case study	Form required by program	
Random number generators:	Random number	Use	RMULT card
	1	for GPSS scheduler	
	2	generate normal random distribution	
	3	tree location distribution	
	4	d.b.h. distribution	
	5	not used	
	6	delay distributions	
Number of days	5 days		
Standard output	every 5th day		Start card

tistics provides detailed information on how the feller/buncher spends its time in the woods. The SAVEVALUE list contains all the totals necessary to calculate productivity if the FORTRAN subroutines cannot be used .

Example:

FBHR = 4,006 = feller hours × 100

FBTRE = 3,785 trees cut

3,785/40.06 × 94.48 trees/hour

```
                              FULL  TREE  FIELD  CHIPPING  SIMULATOR

                                       DEVELOPED  BY  THE
                             NORTH CENTRAL FOREST  EXPERIMENT  STATION
                           FOREST  SERVICE, U. S. DEPT.  OF  AGRICULTURE

                 FOREST  PRODUCTS  MARKETING  AND  UTILIZATION  PROJECT,  DULUTH,  MINNESOTA
                                                   AND  THE
                           FOREST  ENGINEERING  LABORATORY, HOUGHTON,  MICHIGAN

                                                   AUTHORS
                                       DENNIS P. BRADLEY, ECONOMIST
                                       SHARON A. WINSAUER, PROGRAMMER

I.  STAND CHARACTERISTICS.

   2842.00 CU FT. AVERAGE VOLUME PER ACRE.
      5.10 INCHES, AVERAGE DBH.
     60.00 FEET, AVERAGE TREE HEIGHT.
    550.00 AVERAGE NUMBER OF TREES PER ACRE.
      8.90 FEET, AVERAGE TREE SPACING.

II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ANALYST.
  A.  FELLER-BUNCHER.                    1  MACHINE     RUBBER-TIRED TYPE
      MACHINE LIMITATIONS.
        THE ACCUMULATOR-SHEAR WILL TRY TO OBTAIN A LOAD OF UP TO   5.0 TREES
      BUNCH LIMITATIONS DICTATED BY SKIDDER CAPACITY:
        THE FELLER-BUNCHERS TRY TO ACHIEVE SKIDDER BUNCHES WITH A TOTAL SUM OF DIAMETERS EQUAL TO 120.
```

Figure 5.—*Simulation output—system and stand characteristics.*

F E L L E R - B U N C H E R   P R O D U C T I O N   A N D   C O S T   S U M M A R Y

```
I.    A.    40.06    HOURS WORKED BY FELLER-BUNCHER INCLUDING
                298.00    MINUTES OF PERSONAL BREAKS,
                223.50    MINUTES MECHANICAL DELAY,
                178.80    MINUTES NON-MECHANICAL DELAY
      B.        1    FELLER-BUNCHER.    RUBBER-TIRED TYPE.

II.   A.     1490    TOTAL ACCUMULATOR CYCLES COMPLETED - ALL MACHINES.
                  2.54    AVERAGE NUMBER OF TREES PER CYCLE.
                 20.76    AVERAGE VOLUME PER CYCLE - CU.FT.
      B.      348    BUNCHES COMPLETED
                 10.88    AVERAGE NUMBER OF TREES PER BUNCH.
                  4.28    AVERAGE NUMBER OF CYCLES PER BUNCH.
                 88.87    AVERAGE VOLUME PER BUNCH - CU.FT.
      C.     3785    TOTAL TREES FELLED.
      D.  30927.3    TOTAL VOLUME FELLED - CU.FT.
      E.   850.50    TOTAL TONS FELLED
      F.    77027    TOTAL DISTANCE TRAVELED - FEET

III.  A.    37.19    AVERAGE NUMBER OF CYCLES PER MACHINE HOUR.
      B.     8.69    AVERAGE NUMBER OF BUNCHES COMPLETED PER MACHINE HOUR.
      C.    94.48    AVERAGE NUMBER OF TREES FELLED PER MACHINE HOUR.
      D.   772.02    AVERAGE VOLUME FELLED PER MACHINE HOUR.
      E.    21.23    AVERAGE NUMBER OF TONS FELLED PER MACHINE HOUR.
      F.  1922.79    AVERAGE DISTANCE TRAVELED PER MACHINE HOUR - FEET.

IV.   A.   188.28    TOTAL GALLONS OF FUEL USED BY THE FELLER-BUNCHER.
                  4.70    GALLONS PER HOUR.
                   .22    GALLONS PER TON.
                   .61    GALLONS PER CUNIT.
```

```
                                            ***  GPSS/X8  NORMAL COMPLETION OF SIMULATION RUN   ***
RELATIVE CLOCK:      720001      ABSOLUTE CLOCK:      720001
TRANS COUNT:  BLOCK   TRANS,TOTAL     BLOCK   TRANS,TOTAL     BLOCK   TRANS,TOTAL     BLOCK   TRANS,TOTAL     BLOCK   TRANS,TOTAL
              TIMER      0,    1      NXDAY      0,    5          3      0,    5      DAY        0,    5          5      0,    5
                  6      0,    5          7      0,    5          8      0,    5          9      0,    5         10      0,    5
                 11      0,    5         12      0,    5         13      0,    5         14      0,    5         15      0,    5
                 16      0,    5         17      0,    5         18      0,    5         19      0,    5         20      0,    5
                 21      0,    5         22      1,   10      OUTPT      0,    5      ACCFB      0,    1      INIT       0,    1
                 26      0,    1         27      0,    1         28      0,    1         29      0,    1         30      0,    1
              TREE       0, 3786         32      0, 3786         33      0, 3786         34      0, 3786         35      0, 3786
                 36      0,   27         37      0,   27         38      0,   27      OLDST      0, 3759      TDIST      0, 4964
                 41      0, 4964         42      0, 2264      UTST1      0, 4964         44      0, 4964         45      0,    0
              DTST2      0, 4964         47      0, 4964         48      0, 4964         49      0, 3015         50      0, 3015
              DTST3      0, 4964         52      0, 4964         53      0, 3871      FIRST      0, 4964         55      0, 3474
              FELL       0, 3785         57      0, 3785         58      0, 3785         59      0, 3785         60      0, 3785
                 61      0, 3785         62      0, 3785         63      0, 3785         64      0, 3785         65      0, 3785
                 66      0, 3785         67      0, 3785         68      0, 3785         69      0, 3785         70      0, 3785
              ACCFL      0, 1490         72      0, 1457         73      0, 1457         74      0,  629      DTSTA      0, 1457
                 76      0, 1457         77      0, 1445      DTSTB      0, 1457         79      0, 1457         80      0, 1457
                 81      0, 1374         82      0, 1374      DTSTC      0, 1457         84      0, 1457         85      0, 1304
              PBFAR      0, 1457         87      0,  316         88      0,  632         89      0,  316         90      0,  316
                 91      0,  316      TRVPB      0, 1141         93      0, 1141         94      0, 1141         95      0, 1141
                 96      0, 1141         97      0, 1141      DROP       0, 1490         99      0, 1490        100      0, 1490
                101      0, 1490        102      0, 1490        103      0, 1490        104      0, 1490        105      0, 1490
                106      0, 1490        107      0, 1490        108      0, 1490        109      0, 1490        110      0, 1490
                111      0, 1490        112      0, 1490        113      0, 1490        114      0, 1490        115      0,   10
                116      0,   10      NOBRK      0, 1490        118      0,    5        119      0,    5      QUI        0, 1490
                121      0, 1490        122      0, 1490        123      0, 1490        124      0, 1490        125      1, 1490
                126      0, 1489        127      0, 1489        128      0, 1489        129      0, 1489        130      0, 1489
                131      0, 1489        132      0, 1489        133      0, 1489        134      0, 1489        135      0, 1484
              BNCOM      0,   32        137      0,   64        138      0,   32        139      0,   32        140      0,   32
                141      0,   27        142      0,   27        143      0,   27        144      0,   27      BUNCH      0,  348
                146      0,  348        147      0,  348        148      0,  348        149      0,  348        150      0,  348
                151      0,  348        152      0,  348        153      0,  348        154      0,  348        155      0,  348
                156      0,  348        157      0,  348

CURRENT EVENTS CHAIN
TRANS       BDT BLK  PR NBA MARKTIME  SET SDIP    PARAMETERS
  284    720001  23  12  24        1  355           0      0    0    0    0    0    0    0    0    0    0    0
  355         0  22  12   2        1  284           0      0    0    0    0    0    0    0    0    0    0    0
    2    624114 125  10 126        1    2 11        0 623995    7   62 3786    5   94    6   24    0   11  826
                                                    3      0    0    0    0    0    0    0    0    0    0    0

FUTURE EVENTS CHAIN
TRANS       BDT BLK  PR NBA MARKTIME  SET SDIP    PARAMETERS
```

QUEUE STATISTICS

QUEUE NR	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/TRANS	$ AVERAGE TIME/TRANS	TABLE NUMBER	CURRENT CONTENTS
BREAK	1	.04	1490	1475	99.0	20.13	2000.00	0	0
MCDLY	1	.03	1490	1477	99.1	15.42	1766.92	0	0
NMDLY	1	.02	1490	1449	97.2	12.01	436.37	0	0
FBTRV	1	.07	4926	239	4.9	10.94	11.50	0	0
FBSHR	1	.13	3785	0	0.0	24.74	24.74	0	0
FBDRP	1	.03	1490	0	0.0	14.75	14.75	0	0

*** NO GROUPS WERE USED ***

SAVE VALUES

```
SAVEX       NR..........VALUE     NR..........VALUE     NR..........VALUE     NR..........VALUE     NR..........VALUE
         WKDAY              8   DAYS              5   FBHR           4006   BRKTM          29800   DELYM          22350
         DELNM          17880   FBTIM        240391   AVVOL        284200   AVDBH            510   AVHGT             60
         TRPAC            550   NUMFB             0   ACLM1             5   FBTYP              1   BNLM1            120
         FBTRE           3785   FBVOL       3092727   BNCOM           348   FBDIS          77027   FBACC           1490
         LBCFT             55   FBGPH            47   MAX              24   MIN                4   STPLN            660
         PBX                7   PBY              62   XDIF              4   YDIF              24   ACCLM              5
         RUNLM            120   ADLIM             8   PBDIA            31   BDLIM             45   PBTRE              6
         PBEND              0   PBVOL          3307   MVSTP            32   FTRV1            150   FTRV2             50
         FSHR1             25   FSHR2            12   FDRP1            15   FDRP2              9   STPWH             10
```

*** NO MATRICES WERE USED ***

Additional details of the in-woods operations are provided by the GPSS TABLES (figs. 8-10). The cycle time table FBTIM (cycle time starts after the feller/buncher drops one load and ends when it drops the next) shows there were 1,490 cycles with an average cycle time of 161 centi-minutes. Of all 1,490 cycles, 240 cycles or 16 percent took between 100 and 125 centi-minutes .

It should be noted that all of the output was obtained by random processes in the model. Therefore, the output data are themselves a random sample of what could happen. If the model is run again with different random samples, the exact results will be different but will reflect the underlying means and variance of the system. An average over several days or several runs is the best estimate of an actual system .

RELIABILITY

The simulation described here used data obtained in a previous study of mechanized thinning. Three simulation runs were made using different random number sequences to insure different random samples. Simulated production figures were averaged and compared with the productivity observed during the actual thinning (table 6). The greatest error of 14.7 percent appears in cycles/hour with delay. A portion of this error can be attributed to the simulation runs having a higher percent of productive time on the runs made. Other runs, with different random number sequences, would alter the number and duration of delays, hence the cycles/hour. The comparison indicates the model is a reasonably accurate mirror of the real system. Obviously, the better the input data, the more useful the output!

KNOWN GPSS SYSTEMS DIFFERENCES

The program listed in the Appendix is operational on a UNIVAC 1110 under an implentation of GPSS called GPSS-X8, obtained through Use Program Library Interchange (UPLI). It should run under most GPSS Processors with only minor changes. The following should be checked for your system.

INITIAL cards—In GPSS-X8, the INITIAL cards appear last in the deck.

They should be moved to the head of the deck for most other GPSS processors.

JOB CONTROL cards—These are unique to each computer lab and must be obtained locally.

HELP BLOCKS—In GPSS-X8, HELP BLOCKS (line 65-80 in the program) are used to pass an array of up to five integer values to a FORTRAN subroutine. Only a one-way transfer is permitted, the subroutine cannot pass arguments back to GPSS.

Some versions of GPSS do not allow HELP BLOCKS. In this case, the program can be run without lines 48 to 80 and the data obtained instead from the standard output. If some form of HELP BLOCKS are allowed, the HELP BLOCKS formats and the subroutines may have to be changed. See the GPSS manual for your computer installation.

CONCLUSIONS

Most harvesting system changes have relatively complex effects on productivity. The simulation model provides an in-depth look at the operation of this machine in the woods and makes it possible to study the effect of a change in any one system characteristic or stand factor or many changes at the same time. It can also be combined with a model of skidding and chipping operations to provide productivity information for a whole-tree system. Perhaps the greatest value of a GPSS model is the ease with which it can be modified to suit the exact requirements of your system. Although this requires some knowledge of GPSS, it makes simulation an extremely valuable tool.

Table 6.—*Corroboration of simulated productivity with field data*

Field data and simulated productivity	Productive time worked	Trees per hour		Cycles per hour		Average number trees	
		No delays	With delays	No delays	With delays	/Cycle	/Skidbunch
	Percent						
Field data	73	132	94	48	34	2.8	10.1
Simulation runs[1]	78	130	98	51	39	2.5	10.8
(Error)	(6.8)	(−1.5)	(4.1)	(5.8)	(14.7)	(−10.7)	(6.9)

[1]Average of three simulation trials using different random number sequences.

CYCLE TIME (CENTI-MINUTES)

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
FBTIM	1490	161.34	324.50	240391.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
25	1	.06	.0	99.9	.15	-.42
50	83	5.57	5.6	94.4	.31	-.34
75	283	18.99	24.6	75.4	.46	-.26
100	293	19.66	44.3	55.7	.62	-.18
125	240	16.11	60.4	39.6	.77	-.11
150	178	11.95	72.3	27.7	.93	-.03
175	176	11.81	84.2	15.8	1.08	.04
200	103	6.91	91.1	8.9	1.24	.11
225	54	3.62	94.7	5.3	1.39	.19
250	17	1.14	95.8	4.2	1.55	.27
275	8	.53	96.4	3.6	1.70	.35
300	6	.40	96.8	3.2	1.86	.42
325	2	.13	96.9	3.1	2.01	.50
375	1	.06	97.0	3.0	2.32	.65
400	2	.13	97.1	2.9	2.48	.73
425	1	.06	97.2	2.8	2.63	.81
500	1	.06	97.2	2.8	3.10	1.04
550	2	.13	97.4	2.6	3.41	1.20
OVERFLOW	39	2.62	100.0	.0		

VOLUME (CU. FT. x 100) PER ACCUMULATOR HEAD LOAD

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
ACCVL	1490	2075.66	1934.37	3092727.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
500	295	19.80	19.8	80.2	.24	-.81
1000	274	18.39	38.2	61.8	.48	-.55
1500	182	12.21	50.4	49.6	.72	-.29
2000	157	10.54	60.9	39.1	.96	-.03
2500	122	8.19	69.1	30.9	1.20	.21
3000	92	6.17	75.3	24.7	1.45	.47
3500	79	5.30	80.6	19.4	1.69	.73
4000	58	3.89	84.5	15.5	1.93	.99
4500	52	3.49	88.0	12.0	2.17	1.25
5000	56	3.76	91.7	8.3	2.41	1.51
5500	25	1.68	93.4	6.6	2.65	1.77
6000	25	1.68	95.1	4.9	2.89	2.03
6500	13	.87	96.0	4.0	3.13	2.29
7000	17	1.14	97.1	2.9	3.37	2.55
7500	13	.87	98.0	2.0	3.61	2.80
8000	7	.47	98.5	1.5	3.85	3.06
8500	4	.26	98.7	1.3	4.10	3.32
9000	10	.67	99.4	.6	4.34	3.58
9500	1	.06	99.5	.5	4.58	3.84
10000	3	.20	99.7	.3	4.82	4.10
11000	2	.13	99.8	.2	5.30	4.61
11500	3	.20	100.0	.0	5.54	4.87

NUMBER OF TREES PER ACCUMULATOR HEAD LOAD

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
ACCTR	1490	2.54	1.52	3785.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1	537	36.04	36.0	64.0	.39	-1.02
2	314	21.07	57.1	42.9	.78	-.35
3	222	14.90	72.0	28.0	1.18	.30
4	131	8.79	80.8	19.2	1.57	.96
5	286	19.19	100.0	.0	1.97	1.62

NUMBER OF TREES PER SKIDDER BUNCH

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
BTRE	348	10.86	3.57	3779.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1	2	.57	.5	99.4	.09	-2.76
3	3	.86	1.4	98.6	.27	-2.20
4	8	2.30	3.7	96.3	.36	-1.92
5	11	3.16	6.9	93.1	.46	-1.64
6	16	4.60	11.5	88.5	.55	-1.36
7	20	5.75	17.2	82.8	.64	-1.08
8	26	7.47	24.7	75.3	.73	-.80
9	33	9.48	34.2	65.8	.82	-.52
10	40	11.49	45.7	54.3	.92	-.24
11	43	12.36	58.0	42.0	1.01	.03
12	41	11.78	69.8	30.2	1.11	.31
13	32	9.20	79.0	21.0	1.20	.59
14	20	5.75	84.8	15.2	1.29	.87
15	19	5.46	90.2	9.8	1.38	1.16
16	9	2.59	92.8	7.2	1.47	1.44
17	12	3.45	96.3	3.7	1.57	1.72
18	6	1.72	98.0	2.0	1.66	2.00
19	4	1.15	99.1	.8	1.75	2.28
20	1	.28	99.4	.5	1.84	2.56
21	2	.57	100.0	.0	1.93	2.84

Figure 9.—*Simulation output.*

VOLUME (CU. FT. X 100) PER SKIDDER BUNCH

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
BVOL	348	8877.64	4055.18	3089420.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1000	2	.57	.5	99.4	.11	-1.94
2000	5	1.44	2.0	98.0	.22	-1.70
3000	13	3.74	5.7	94.3	.33	-1.45
4000	14	4.02	9.8	90.2	.45	-1.20
5000	21	6.03	15.8	84.2	.56	-.95
6000	32	9.20	25.0	75.0	.67	-.71
7000	45	12.93	37.9	62.1	.78	-.46
8000	33	9.48	47.4	52.6	.90	-.21
9000	27	7.76	55.2	44.8	1.01	.03
10000	32	9.20	64.4	35.6	1.13	.27
11000	20	5.75	70.1	29.9	1.24	.52
12000	31	8.91	79.0	21.0	1.35	.77
13000	14	4.02	83.0	17.0	1.46	1.02
14000	18	5.17	88.2	11.8	1.58	1.26
15000	16	4.60	92.8	7.2	1.69	1.51
16000	7	2.01	94.8	5.2	1.80	1.76
17000	9	2.59	97.4	2.6	1.91	2.00
18000	1	.28	97.7	2.3	2.03	2.25
19000	2	.57	98.3	1.7	2.14	2.50
20000	4	1.15	99.4	.5	2.25	2.74
22000	1	.28	99.7	.2	2.48	3.24
23000	1	.28	100.0	.0	2.59	3.48

Figure 10.—*Simulation output.*

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APPENDIX A

VARIABLE LISTS AND DEFINITIONS

DEFINITIONS

IMPLICIT TIME UNIT—CENTI-MINUTE

Model Segments, Transactions, and Parameters

Segment 1—TIMER
- Transactions—1 time keeper
- Parameters—None

Segment 2—FELLER/BUNCHER
- Transactions—Feller/buncher
- Parameters
  - P1—not currently used
  - P2—clock time marking cycle
  - P3—current X coordinate of the feller/buncher
  - P4—current Y coordinate of the feller/buncher
  - P5—tree number being cut
  - P6—X coordinate of the tree
  - P7—Y coordinate of the tree
  - P8—tree diameter
  - P9—distance from feller/buncher to tree
  - P10—end of strip indicator
  - P11—sum of tree diameters in current accumulator load
  - P12—volume of current accumulator load
  - P13—number of trees in accumulator load

FUNCTIONS

DBH	Distribution of tree diameters in the stand
HYP	Distribution used to calculate the leng of the hypotenuse of a right triangle
SNORM	Distribution used to obtain a normal distribution for sampling with a mear 0, variance = 1, lower end truncated
YCDIF	Distribution of the distance along the strip from current tree to next tree; i. difference in Y coordinates
MCDLY	Distribution of the occurrence and duration of mechanical delay
NMDLY	Distribution of the occurrence and duration of nonmechanical delays

SAVEVALUES

ACCLM	Accumulator head limit of this load, number of trees
ACLM1	Accumulator head limit, maximum number of trees
ADLIM	Accumulator distance limit, maximu distance feller will travel to add ano tree to load, feet
AVDBH	Mean stand diameter, inches × 100
AVHGT	Mean stand height, feet
AVVOL	Mean vol/acre, cu ft × 100

BDLIM	Bunch distance limit, maximum distance feller will travel to add trees to a partial skidder bunch, feet
BNCOM	Number of skidder bunches complete and ready for skidding
BNLM1	Maximum sum of diameter for skidder bunch size limit, inches
BRKTM	Total time spent on breaks, centi-minutes
BUNLM	Current bunch size limit—sum of diameter, inches
DAYS	Number of days worked
DELNM	Total time lost to nonmechanical delays, centi-minutes
DELYM	Total time lost to mechanical delay, centi-minutes
FBACC	Total number of feller/buncher accumulator loads
FBDIS	Total distance feller has traveled, feet
FBGPH	Feller/buncher fuel usage, gal/hr × 10
FBHR	Total time feller has worked, hours × 100
FBTIM	Total time feller has been on job, minutes × 100
FBTRE	Total trees cut
FBTYP	Feller/buncher type code, rubber-tired = 1
FBVOL	Total volume cut, cu ft × 100
FDRP1	Mean drop time, centi-minutes
FDRP2	Standard deviation drop time, centi-minutes
FSHR1	Mean shear time, centi-minutes
FSHR2	Standard deviation shear time, centi-minutes
FTRV1	Mean travel speed, ft/min
FTRV2	Standard deviation travel speed, ft/min
LBCFT	Density of stand species, lb/cu ft
MAX	Longest distance of travel (X or Y direction), ft
MIN	Shortest distance of travel (X or Y direction), ft
MVSTP	Distance feller travels between strips, ft
NUMFB	Number of feller/bunchers on job
PBDIA	Partial bunch sum of diameter, inches
PBEND	Partial bunch end of strip indicator
PBTRE	Partial bunch number of trees
PBVOL	Partial bunch—current volume, cu ft × 100
PBX	Partial bunch X coordinate
PBY	Partial bunch Y coordinate
STPLN	Length of strip, ft
STPWH	Width of strip, ft
STRIP	Number of strips harvested
TRPAC	Mean stand density, trees/acre
WKDAY	Length of work shift, hours
XDIF	Distance between the feller's current location and its next location across strip, ft
YDIF	Distance between the feller's current location and its next location along strip, ft

SWITCHES

COFFE	Set by timer to indicate coffee breaks
DAY	Set by timer to indicate beginning of workday
LUNCH	Set by timer to indicate lunch break

TABLES

ACCTR	Trees per accumulator load
ACCVL	Volume per accumulator load, cu ft × 100
BDIA	Sum of diameter of trees in skid bunch, inches
BTRE	Trees per skidder bunch
BVOL	Volume per skidder bunch, cu ft × 100
FBTIM	Cycle time for feller/buncher from drop to drop, including delays, centi-minutes

QUEUES

BREAK	Coffee and lunch break time
FBDRP	Swing and drop time
FBSHR	Position and shear time
FBTRV	All travel time
MCDLY	Mechanical delays
NMDLY	Nonmechanical delays

VARIABLES

ACCLM	Accumulator head limit, number of trees
BREAK	Time between breaks, centi-minutes
BRKTM	Time spent on breaks, centi-minutes
BUNLM	Skidder bunch limit, sum of diameter, inches
DELNM	Nonmechanical delay time, centi-minutes
DELYM	Mechanical delay time, centi-minutes
FBDRP	Swing and drop time, centi-minutes
FBHR	Total time, hours × 100
FBSHR	Shear time, centi-minutes
FBTRV	Travel time, centi-minutes
HYP	Length of hypotenuse of a right triangle
MCDLY	Length of mechanical delay
NEWY	Y coordinate when skidder changes strips
NIGHT	Remainder of 24 hours after work shift, centi-minutes

NMDLY	Length of nonmechanical delay, centi-minutes
NXDIF	Used to make distance in X direction positive
NYDIF	Used to make distance in Y direction positive
RATIO	Ratio between the legs of a right triangle
SPEED	Feller/buncher travel speed, ft/min
TDIAM	Tree diameter, inches
TVOL	Tree volume, cu ft × 100
WKDAY	Length of work shift, centi-minutes
XCORD	X coordinate (across strip) of tree location, ft
YCORD	Y coordinate (down strip) of tree distance, ft
XDIF	X distance from feller/buncher to tre
YDIF	Y distance from feller/buncher to tre
XDIF1	X distance from feller/buncher to par bunch
YDIF1	Y distance from feller/buncher to par bunch

APPENDIX B

PROGRAM LISTING

```
/ * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
*          FELLER BUNCHER SIMULATOR
*               UPDATED  JAN 1981
*
*
*        U.S. FOREST SERVICE, NORTH CENTRAL FOREST EXPERIMENT STATION
*        MARKETING PROJECT, DULUTH, MINNESOTA
*        ENGINEERING PROJECT, HOUGHTON, MICHIGAN
*
*          AUTHORS:  SHARON A. WINSAUER
*                    DENNIS P. BRADLEY
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
*                   MASTER TIMER AND REPORT GENERATOR
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
*          THIS SEGMENT CONTROLS THE STOP AND START OF THE FELLER BUNCHER,
*            THE HOURS WORKED  PER DAY, X$WKDAY, AND THE NUMBER OF
*            DAYS WORKED(ARGUMENT A ON START CARD)
*
*          IT ALSO CALCULATES OUTPUT VALUES,VALUES TO BE SENT TO HELP BLOCKS,
*
*
*
 WKDAY VARIABLE    X$WKDAY*6000              WORKDAY IN CENTIMINUTES
 BREAK FVARIABLE   V$WKDAY/4                 TIME BETWEEN BREAKS
 NIGHT VARIABLE    (24-X$WKDAY)*6000         REST OF 24 HOURS IN CENTIMINUTES
*
 1   TIMER GENERATE    ,,,1,12
 2   NXDAY SAVEVALUE   DAYS+,1                   NUMBER OF CURRENT WORKING DAY
 3         LOGIC S     DAY
 4   DAY   ADVANCE     V$BREAK                   TIME FOR COFFEE BREAK
 5         LOGIC S     COFFE
 6         ADVANCE     V$BREAK                   WORK UNTIL LUNCH TIME
 7         LOGIC S     LUNCH
 8         ADVANCE     V$BREAK                   AFTERNOON COFFEE
 9         LOGIC S     COFFE
10         ADVANCE     V$BREAK                   END OF WORK DAY
11         LOGIC R     DAY
12         ADVANCE     V$NIGHT                   WAIT UNTIL NEXT MORNING
*
*
* * * *  HELP BLOCKS  GENERATE REPORT AT END OF EACH DAY
*
*
* * * * REPORT VARIABLES
*
13         SAVEVALUE   FBHR,V$FBHR               HOURS FB HAVE WORKED
14         SAVEVALUE   BRKTM,V$BRKTM             TIME FB SPENT ON BREAKS IN MIN*100
15         SAVEVALUE   DELYM,V$DELYM             MECHANICAL DELAY TIME OF FB
16         SAVEVALUE   DELNM,V$DELNM             NON-MECHANICAL DELAY TIME OF FB
 FBHR  FVARIABLE   X$FBTIM/60
 BRKTM FVARIABLE   QT$BREAK*QC$BREAK
 DELYM FVARIABLE   QT$MCDLY*QC$MCDLY
 DELNM FVARIABLE   QT$NMDLY*QC$NMDLY
```

```
*  *  *  *  STAND DATA AND MACHINE CHARACTERISTICS REPORT
*
17          HELP        SYSTM,XSAVVOL,XSAVDBH,XSAVHGT,XSTRPAC
18          HELP        SYSTM,XSNUMFB,XSACLM1,XSFBTYP,XSBNLMI
*                 AVE VOL,AVE DBH,AVE HEIGHT,TREES/ACRE,NUM OF FELLERS
*              FB ACCUMULATOR HEAD LIMIT,FB TYPE,SKIDDER BUNCH LIMIT
*
*  *  *  *  FELLER BUNCHER  PRODUCTION REPORT
*
19          HELP        FELBN,XSNUMFB,XSFBTYP,XSBRKTM,XSDELYM,XSDELNM
*             NUM OF FELLER BUNCHERS, FB TYPE,BREAKTIME,DELAY TIME
*
20          HELP        FELBN,XSFBTRE,XSFBVOL,XSBNCOM,XSFBHR,XSFBDIS
*             TOT TREES,TOT VOL,SKID BUNCHES COMPLETED,FB HOURS,TOT DIST TRAVELED
*
21          HELP        FELBN,XSFBACC,XSLBCFT,XSFBVOL,XSFBGPH
*             NUM OF ACC LOADS, WOOD DENSITY LB/CUFT, TOT VOL, GAL PER HOUR USED
*
22          SPLIT       1,NXDAY
23    OUTPT TERMINATE   1
*
*  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
*
*           GENERAL FUNCTIONS NEEDED IN MODEL
*
*  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -  -
*
*  *  *  *  FNSSNORM IS USED TO OBTAIN A SAMPLING OF AN APPROXIMATELY
*              NORMAL DISTRIBUTION OF MEAN 0 AND STANDARD DEV 1
*
*            NOTE: TO AVOID DATA LOSS FROM INTERGERAZATION.
*                  FUNCTION VALUES HAVE BEEN
*                  MULTIPLIED BY 10
*            *  *  USE     MEAN+(FNSSNORM * S.DEV)/10
*
*            NOTE: LOWER END OF FUNCTION HAS BEEN TRUNCATED
*                  TO AVOID NEGATIVE ADVANCE BLOCKS
*                  WHEN STANDARD DEVIATIONS ARE LARGE
*
*
SNORM FUNCTION    RN2,C20
0,-15/.0668,-15/.1151,-12/.1587,-10/.2119,-8/.2742,-6/.3446,-4
.4207,-2/.5,0/.5793,2/.6544,4/.7258,6/.7881,8/.8413,10/.8849,12
.9332,15/.9772,20/.9938,25/.9986,30/.9999,40/1.,50
*
*
*            THIS FUNCTION IS USED FOR DISTANCES FOR THE FELLER BUNCHER
*
*  *  *  *  VSHYP GIVES THE LENGTH OF THE HYPOTENUSE OF A RT TRIANGLE
*              WITH SIDES EQUAL TO XSMAX AND XSMIN
*
RATIO VARIABLE    XSMAX*10/XSMIN
*
HYP   VARIABLE    XSMAX*FNSHYP/1000
*
HYP   FUNCTION    VSRATIO,D24
10,1414/11,1351/12,1302/13,1262/14,1229/15,1202/16,1179/17,1160/18,1144
19,1130/20,1118/22,1098/24,1083/26,1071/28,1062/30,1054/35,1040/40,1031
50,1020/60,1014/70,1010/80,1008/100,1005/20000,1000
*
```

```
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
* * *  ACCUMULATING OR SINGLE STEM RUBBER TIRED FELLER BUNCHER SEGMENT
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*
*
*      THIS SEGMENT MODELS A RUBBER-TIRED FELLER BUNCHER WITH
*      AN ACCUMULATING SHEAR ATTACHED TO THE FRONT
*
*      THE FELLER TRAVELS FROM TREE TO TREE, CUTTING EACH
*      TREE, GENERALLY CUTTING A REASONABLY WIDE
*      SWATH OR STRIP THROUGH THE WOOD
*
*      THE FELLER COMBINES MULTIPLE ACCUMULATOR HEAD
*      BUNCHES TO OBTAIN BUNCHES LARGE ENOUGH FOR
*      THE SKIDDER.
*
*
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*
* - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*              FELLER BUNCHER PARAMATER ASSIGNMENTS
*
*         P1     NOT USED
*         P2     CLOCK TIME
*         P3     X COORD OF FELLER BUNCHER
*         P4     Y COORD OF FELLER BUNCHER
*         P5     TREE NUMBER
*         P6     X COORD OF TREE
*         P7     Y COORD OF TREE
*         P8     TREE DIAMETER
*         P9     DIST FROM FB TO TREE
*         P10    END OF STRIP INDICATOR
*         P11    SUM OF DIAMETER OF LOAD
*         P12    SUM OF VOLUME OF LOAD
*         P13    NUMBER OF TREES IN LOAD
*
* *    DEFINING VARIABLES FOR FELLER BUNCHER
*
*
 NEWY   VARIABLE   P7-X$STPLN          NEW Y CORD AT BEGINNING OF STRIP
 XDIF   VARIABLE   P6-P3               X DIST FB TO TREE
 YDIF   VARIABLE   P7-P4               Y DIST FB TO TREE
 XDIF1  VARIABLE   X$PBX-P3            X DIST FB TO PARTIAL BUNCH
 YDIF1  VARIABLE   X$PBY-P4            Y DIST FB TO PARTIAL BUNCH
 NXDIF  VARIABLE   -X$XDIF             USED TO CONVERT SIGNED
 NYDIF  VARIABLE   -X$YDIF                   DISTANCE TO MAGNITUDES
*
*
* * *  OUTPUT TABLES FOR FELLER BUNCHER
 FBTIM  TABLE      MP2,0,25,25         OUTPUT TABLES FOR FB
 ACCVL  TABLE      P12,0,500,25        CYCLES
 ACCTR  TABLE      P13,0,1,12
*
 BDIA   TABLE      P11,0,5,30          TABLES OF SKIDDER BUNCHES
 BTRE   TABLE      P13,0,1,25          CREATED
 BVOL   TABLE      P12,0,1000,25
```

```
        * * * *  GENERATE FELLER BUNCHER, INITIALIZE ACC HEAD
        *                AND ASSIGN ACCUMULATOR AND BUNCH SIZE LIMITS
        *
 24     ACCFB GENERATE   ,,,1,10,15
        *
 25     INIT  ASSIGN     11,0                 INITILIZE ACCUMULATOR HEAD
 26           ASSIGN     12,0
 27           ASSIGN     13,0
 28           MARK       2                    MARK START OF CYCLE
 29           SAVEVALUE  ACCLM,V$ACCLM        MAXIMUM ACC LOAD
 30           SAVEVALUE  BUNLM,V$BUNLM        MAXIMUM BUNCH SIZE
        *
        *
        *
        * * * * TREE     CREATE NEXT TREE
        *
 31     TREE  ASSIGN     5+,1                 TREE NUMBER
 32           ASSIGN     6,V$XCORD            X COORDINATE OF TREE
 33           ASSIGN     7,V$YCORD            Y COORDINATE OF TREE
 34           ASSIGN     8,V$TDIAM            DBH OF TREE
        *
        *
        *
        * * * *  ? IS TREE IN A NEW STRIP ?   IF NOT GO TO OLDST
        *                   IF A NEW STRIP - REASSIGN Y CORD AND MARK END OF
        *                   STRIP P10
        *
 35           TEST G     P7,X$STPLN,OLDST         ? NEW STRIP ?
 36           ASSIGN     7,V$NEWY             NEW Y COORD
 37           ASSIGN     10,1                 END OF STRIP INDICATOR
 38           TRANSFER   ,ACCFL
        *
        *
        *
        * * * * OLDSTP - THE FB DID NOT MOVE TO A NEW STRIP.  SEE IF THERE IS
        *                ROOM IN ACC HEAD FOR ANOTHER TREE - IF SO SEE HOW FAR
        *                AWAY TREE IS.
        *
 39     OLDST TEST L     P13,X$ACCLM,ACCFL        IF ACCHEAD FULL - GO TO ACCFL
        *
 40     TDIST SAVEVALUE  XDIF,V$XDIF          CALCULATE DISTANCE TO TREE
 41           TEST L     X$XDIF,0,DTST1
 42           SAVEVALUE  XDIF,V$NXDIF
 43     DTST1 SAVEVALUE  YDIF,V$YDIF
 44           TEST L     X$YDIF,0,DTST2
 45           SAVEVALUE  YDIF,V$NYDIF
 46     DTST2 SAVEVALUE  MAX,X$XDIF
 47           SAVEVALUE  MIN,X$YDIF
 48           TEST L     X$MAX,X$MIN,DTST3
 49           SAVEVALUE  MIN,X$XDIF
 50           SAVEVALUE  MAX,X$YDIF
 51     DTST3 ASSIGN     9,X$MAX
 52           TEST G     X$MIN,0,FIRST
 53           ASSIGN     9,V$HYP              DIST FROM FB TO TREE
        *
```

```
      * * * *  FIRST  IF THIS IS THE FIRST TREE IN THE ACCUMULATOR
      *                 GO TO FELL AND FELL THE TREE.    IF IT IS NOT
      *                 THE FIRST TREE SEE HOW FAR AWAY THE TREE IS.
      *                 IF TOO FAR GO TO ACCFL - THIS IS A COMPLETE LOAD
      *
54     FIRST TEST G      P11,0,FELL        ? IF FIRST TREE ?
55           TEST L      P9,X$ADLIM,ACCFL ? TREE TOO FAR?
      *
      *
      * * * *  FELL       FELLER BUNCHER TRAVELS TO TREE AND FELLS IT
      *                 ADDS TREE TO ACCUMULATOR HEAD AND RECORDS PRODUCTION
      *                 DATA, THEN FB LOOKS AT NEXT TREE
      *
56     FELL  QUEUE       FBTRV
57           ADVANCE     V$FBTRV           FELLER TRAVELS TO TREE
58           DEPART      FBTRV
59           ASSIGN      4,P7              TREE COORDINATES BECOME
60           ASSIGN      3,P6              FB COORDIANATES
61           QUEUE       FBSHR
62           ADVANCE     V$FBSHR           FB SHEARS TREE
63           DEPART      FBSHR
      *
      *                                    FB ADDS TREE TO ACC HEAD
64           ASSIGN      11+,P8            SUM OF DIA
65           ASSIGN      13+,1             NO OF TREES
66           ASSIGN      12+,V$TVOL        TOTAL LOAD VOL
      *
67           SAVEVALUE   FBTRE+,1          RECORD PRODUCTION OF FELLER
68           SAVEVALUE   FBVOL+,V$TVOL
69           SAVEVALUE   FBDIS+,P9
70           TRANSFER    ,TREE
      *
      *
      * * * *  ACCFL  - ACCUMULATOR FULL
      *                 ? HAS A PARTIAL BUNCH BEEN STARTED ?
      *                 IF NO PARTIAL BUNCH GO TO DROP-DROP TREES AT CURRENT LOCATION.
      *                 IF THERE IS A PARTIAL BUNCH SEE HOW FAR AWAY IT IS
      *
71     ACCFL TEST G      X$PBDIA,0,DROP    HAS A PARTIAL BUNCH BEEN STARTED?
      *                                    IF NOT - GO TO DROP
72           SAVEVALUE   XDIF,V$XDIF1      CALCULATE DISTANCE FROM FB
73           TEST L      X$XDIF,0,DTSTA    TO PARTIAL BUNCH
74           SAVEVALUE   XDIF,V$NXDIF
75     DTSTA SAVEVALUE   YDIF,V$YDIF1
76           TEST L      X$YDIF,0,DTSTB
77           SAVEVALUE   YDIF,V$NYDIF
78     DTSTB SAVEVALUE   MAX,X$XDIF
79           SAVEVALUE   MIN,X$YDIF
80           TEST L      X$MAX,X$MIN,DTSTC
81           SAVEVALUE   MAX,X$YDIF
82           SAVEVALUE   MIN,X$XDIF
83     DTSTC ASSIGN      9,X$MAX
84           TEST G      X$MIN,0,PBFAR
85           ASSIGN      9,V$HYP                     DISTANCE FB TO PARTIAL BUNCH
      *
      *
      * * * *  PBFAR  PARTIAL BUNCH TOO FAR?
      *                 IF P BUNCH IS NOT TOO FAR AWAY TRAVEL TO  PARTIAL
      *                 BUNCH-TRVPB AND DROP LOAD, IF IT IS TOO FAR
      *                 START NEW BUNCH RIGHT HERE, SEND AN OFFSPRING OF SPLIT BLOCK
      *                 OVER TO MAKE LAST PARTIAL BUNCH COMPLETE
```

```
 86   PBFAR TEST G      P9,XSBDLIM,TRVPB   IS PARTIAL BUNCH TOO FAR ?
     *
 87         PRIORITY    16
 88         SPLIT       1,BUNCH            OFFSPRING GOES TO MAKE LAST BUNCH
 89         PRIORITY    10                 COMPLETE WHILE FB DROPS TREES
 90         BUFFER                         HERE AND STARTS NEW BUNCH
 91         TRANSFER    ,DROP
     *
     *
     *
     * * * * TRVPB - TRAVEL TO PARTIAL BUNCH
     *
 92   TRVPB QUEUE       FBTRV
 93         ADVANCE     V$FBTRV            FB TRAVELS TO PART BUNCH
 94         DEPART      FBTRV
 95         ASSIGN      3,X$PBX            PB COORDINATES BECOME FB COORDINATES
 96         ASSIGN      4,X$PBY
 97         SAVEVALUE   FBDIS+,P9
     *
     * * * * DROP -     FELLER DROPS TREES IN ACC HEAD
     *                   EITHER ADDING TO EXISTING PARTIAL BUNCH OR
     *                   STARTING A NEW BUNCH
     *
 98   DROP  QUEUE       FBDRP
 99         ADVANCE     V$FBDRP            DROP TREES FROM ACC HEAD
100         DEPART      FBDRP
101         SAVEVALUE   PBDIA+,P11         TOTAL SUM OF DIAM IN BUNCH
102         SAVEVALUE   PBTRE+,P13         TOTAL NUMBER OF TREES
103         SAVEVALUE   PBEND,P10          STRIP END INDICATOR
104         SAVEVALUE   PBVOL+,P12         TOTAL VOL
105         SAVEVALUE   PBX,P3             X COORD OF BUNCH
106         SAVEVALUE   PBY,P4             Y COORD OF BUNCH
     *
     * * *  DELAY    IF A DELAY IS TO OCCUR IT HAPPENS HERE
107         QUEUE       MCDLY
108         ADVANCE     V$MCDLY            MECHANICAL DELAY
109         DEPART      MCDLY
110         QUEUE       NMDLY
111         ADVANCE     V$NMDLY            NONMECHANICAL DELAY
112         DEPART      NMDLY
     * * *                   CHECK IF TIME FOR BREAK
113         QUEUE       BREAK
114         GATE LS     COFFE,NOBRK        CHECK IF BREAK TIME
115         ADVANCE     1500               15 MIN COFFEE BREAK
116         LOGIC R     COFFE
117   NOBRK GATE LS     LUNCH,QUIT         CHECK IF LUNCH TIME
118         ADVANCE     3000
119         LOGIC R     LUNCH
```

```
          * * *  QUIT - TABULATE TIME ON BREAKS AND CHECK IF ITS TIME TO QUIT
          *
120        QUIT   SAVEVALUE   FBTIM+,MP2         TABULATE CYCLE TIME
121               DEPART      BREAK
          *
122               SAVEVALUE   FBACC+,1           KEEP TRACK OF NUMBER OF ACC LOADS
123               TABULATE    FBTIM              TABULATE TIME AND PRODUCTION
124               TABULATE    ACCVL
125               TABULATE    ACCTR
126               GATE LS     DAY                IF SHIFT IS OVER, STOP TIL TOMORROW
          *                                      REINITILIZE ACC HEAD
127               MARK        2                  MARK START OF CYCLE
128               ASSIGN      11,0
129               ASSIGN      12,0
130               ASSIGN      13,0
131               ASSIGN      10,0
132               MARK        2
133               SAVEVALUE   ACCLM,VSACCLM      SET NEW ACC HEAD LIMIT
          *
          *
          * * *  ? IS THIS A COMPLETE BUNCH OR THE END OF A STRIP ?
          *                  IF SO GO TO BNCOM TO COLLECT BUNCH DATA
          *                  IF NOT A COMPLETE BUNCH
          *                  OR THE END OF A STRIP - GO BACK TO FELL NEXT TREE
          *
134               TEST L      X$PBDIA,X$BUNLM,BNCOM  IS BUNCH COMPLETE ?
135               TEST G      X$PBEND,0,TDIST        IS IT THE END OF A STRIP ?
          *
          *
          *
          * * * BNCOM - BUNCH COMPLETE  OFFSPRING GOES TO COMPLETE
          *                  BUNCH WHILE PARENT -FELLER BUNCHER- GOES TO CUT NEXT TREE
          *
136        BNCOM  PRIORITY    16
137               SPLIT       1,BUNCH
138               PRIORITY    10
139               BUFFER
140               TEST GE     X$PBEND,1,TDIST    IF END OF STRIP
141               ASSIGN      4,P7               CORRECT DISTANCE TO NEW STRIP
142               ASSIGN      3,P6
143               ASSIGN      3+,X$MVSTP         ADD DISTANCE BETWEEN STRIPS
144               TRANSFER    ,TDIST
          *
```

```
          *  *  *  *   BUNCH =   BUNCH IS DESIGNATED COMPLETE AND READY
          *                       FOR SKIDDER TO PICK UP
          *
          *                      BUNCH IS CONSIDERED COMPLETE WHEN IT IS BIG
          *                       ENOUGH FOR THE SKIDDER, OR IF P BUNCH IS TOO FAR
          *                       FROM FELLER BUNCHER,OR FELLER BUNCHER HAS
          *                       REACHED THE END OF A STRIP
          *
  145      BUNCH SAVEVALUE   BNCOM+,1
          *                                     MAKE P BUNCH XTION INTO ACTIVE XTION
  146            ASSIGN      12,XSPBVOL         VOLUME OF BUNCH
  147            ASSIGN      11,XSPBDIA         SUM OF DIAM
  148            ASSIGN      13,XSPBTRE         TOTAL NUM OF TREES
  149            ASSIGN      4,XSPBY            Y COORD DOWN STRIP
          *
  150            SAVEVALUE   PBDIA,0            REINITIALIZE PARTIAL BUNCH
  151            SAVEVALUE   PBTRE,0
  152            SAVEVALUE   PBVOL,0
  153            SAVEVALUE   BUNLM,V$BUNLM      SET BUNCH LIMIT
          *
          *                                     RECORD BUNCH PRODUCTION
  154            TABULATE    BDIA
  155            TABULATE    BTRE
  156            TABULATE    BVOL
  157            TERMINATE
          *  *  *  *  *  *  INPUT DATA
          *
          *
           FBTRV FVARIABLE   P9*100/V$SPEED            TRAVEL TIME (DIST/SPEED) IN CENTIMIN
          *                                            P9 = DISTANCE
           SPEED FVARIABLE   X$FTRV1+X$FTRV2*FN$SNORM/10      TRAVEL SPEED
           FBSHR FVARIABLE   X$FSHR1+X$FSHR2*FN$SNORM/10      POSITION AND SHEAR TIME
           FBDRP FVARIABLE   X$FDRP1+X$FDRP2*FN$SNORM/10      SWING AND DROP TIME
          *
           ACCLM FVARIABLE   X$ACLM1                          MAX ACC LOAD  NUM OF TREES
           BUNLM FVARIABLE   X$BNLM1                          MAX BUNCH SIZE = SUM OF DIA
          *
           XCORD FVARIABLE   (X$STPWH+1)*RN3/1000      X COORDINATE OF TREE
           YCORD FVARIABLE   FN$YCDIF+P7               Y COORDINATE OF TREE
           TDIAM FVARIABLE   FN$DBH                    DIAMETER OF TREE
           TVOL  FVARIABLE   (186*P8*P8-283)/10        TREE VOL IN TERM OF DIA(P8)
          *                                            .01 CU FT
           MCDLY FVARIABLE   FN$MCDLY                  MECHANICAL DELAY
           NMDLY FVARIABLE   FN$NMDLY                  NON-MECHANICAL DELAY
          *
```

```
* * * * *  DEFINING FUNCTIONS
*
*      THIS INPUT DATA WAS OBTAINED FROM TIME STUDIES CARRIED OUT IN 1974
*
 YCDIF FUNCTION    RN3,D10                YDIST FROM CURRENT TREE TO NEXT TREE
.18,0/.48,2/.64,4/.76,6/.84,8/.88,10/.92,12/.95,14/.98,16/1.,18
*
*
 DBH   FUNCTION    RN4,C11                DIAMETER DISTRIBUTION
0,2/.254,4/.497,6/.783,8/.869,10/.932,12/.964,14/.984,16/.995,18/.999,20
1.0,22
*
 NMDLY FUNCTION    RN6,C8                 NON-MECHANICAL DELAY
0,0/.973,0/.982,100/.987,200/.992,500/.996,1000/.999,2000/1.0,5000
*
 MCDLY FUNCTION    RN6,C5                 MECHANICAL DELAY
0,0/.994,0/.996,500/.998,1000/1.0,5000
*
* * * * * *  INITIAL CONDITIONS FOR THE STAND
*
       INITIAL     X$AVDBH,510            AVE STAND DBH (IN*100)
       INITIAL     X$AVVOL,284200         STAND VOL (.01 CU FT/ACRE)
       INITIAL     X$AVHGT,60             AVE TREE HEIGHT (FT)
       INITIAL     X$TRPAC,550            TREES/ACRE
       INITIAL     X$STPLN,660            STRIP LENGTH (FT)
       INITIAL     X$STPWH,10             STRIP WIDTH (FT)
       INITIAL     X$MVSTP,32             DISTANCE BETWEEN STRIPS (FT)
       INITIAL     X$LBCFT,55             WOOD DENSITY LB/CU FT - GREEN
       INITIAL     X$WKDAY,8              HOURS IN A WORK SHIFT
*
* * * * * *  INITIAL CONDITIONS FOR THE RUBBER TIRED FELLER/BUNCHER
*
       INITIAL     X$ADLIM,8              ACCUMULATOR DISTANCE LIMIT
       INITIAL     X$BDLIM,45             BUNCH DISTANCE LIMIT
       INITIAL     X$FBGPH,47             FUEL CONSUMPTION (GAL PER HR + 10)
       INITIAL     X$FTRV1,150            MEAN TRAVEL SPEED (FT/MIN)
       INITIAL     X$FTRV2,50             ST. DEV. TRAVEL SPEED (FT/MIN)
*
       INITIAL     X$FSHR1,25             MEAN SHEAR TIME (CENT MINUTES)
       INITIAL     X$FSHR2,12             ST. DEV. SHEAR TIME
       INITIAL     X$FDRP1,15             MEAN DROP TIME (CENT MINUTES)
       INITIAL     X$FDRP2,9              ST. DEV. DROP TIME
       INITIAL     X$ACLM1,5              MAXIMUM # TREES IN ACC HEAD
*
       INITIAL     X$BNLM1,120            MAX SKIDDER BUNCH -SUM OF DIA (IN)
       INITIAL     X$FBTYP,1              RUBBER TIRED FELLER BUNCHER CODE
* * * * * *  INITIAL CONDITIONS FOR THE RUN
       RMULT       ,,83,151,,701
       START       5,,5,1
       END
```

```
      SUBROUTINE SYSTM(IX)
      DIMENSION IX(5)
      DATA I/0/
C
    1 FORMAT(1H1,43X,'FULL  TREE  FIELD  CHIPPING  ',
     A 'SIMULATOR'/1H0,58X,'DEVELOPED  BY  THE'/1H ,46X,'NORTH CENTRAL '
     B,'FOREST  EXPERIMENT  STATION'/1H ,44X,'FOREST  SERVICE, U. S. DEP
     CT.  OF  AGRICULTURE'//1H0,29X, 'FOREST  PRODUCTS  MARKETING  AND
     TUTILIZATION  PROJECT,  DULUTH,  MINNESOTA'/1H ,61X,'AND  THE'/1H ,
     E40X,'FOREST  ENGINEERING  LABORATORY, HOUGHTON,  MICHIGAN'/1H0,62X
     F,'AUTHORS '/1H ,52X,'DENNIS P. BRADLEY, ECONOMIST'/1H ,51X,'SHARON
     G A. WINSAUER, PROGRAMMER'//)
C
    2 FORMAT(1H0,'I.  STAND CHARACTERISTICS.'//1H0, F12.2,' CU FT. ',
     A  'AVERAGE VOLUME',
     B' PER ACRE.'/1H0,F12.2,' INCHES, AVERAGE DBH.'/1H0,F12.2,' FEET,',
     C' AVERAGE TREE HEIGHT.'/1H0,F12.2,' AVERAGE NUMBER OF TREES ',
     D'PER ACRE.'/1H0,F12.2,' FEET, AVERAGE TREE SPACING.'/)
C
    3 FORMAT(1H0,'II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ',
     A'ANALYST.'//1H ,2X,'A.  FELLER-BUNCHER.',10X ,I10,'  MACHINE',
     B  5X,'TRACKED TYPE-ROTATABLE BOOM WITH ACCUMULATOR SHEAR'
     C  , //9X,'MACHINE LIMITATIONS '/)
C
    4 FORMAT(1H0,'II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ',
     A'ANALYST.'//1H ,2X,'A.  FELLER-BUNCHER.',10X ,I10,'  MACHINE',
     B5X,'RUBBER-TIRED TYPE',//,9X,'MACHINE LIMITATIONS. '/)
C
    5 FORMAT(1H , 14X, 'THE SHEAR CAN HANDLE ONLY ONE TREE.')
C
    6 FORMAT( 1H , 10X, 'THE ACCUMULATOR-SHEAR WILL TRY TO OBTAIN',
     A ' A LOAD OF UP TO',F6.1,' TREES')
C
    7 FORMAT(1H0,8X,'BUNCH LIMITATIONS DICTATED BY SKIDDER CAPACITY:'/
     A1H0, 10X,'THE FELLER-BUNCHERS TRY TO ACHIEVE'
     B ' SKIDDER BUNCHES WITH A TOTAL SUM OF DIAMETERS EQUAL TO',
     C F6.1, ' INCHES')
C
C
      X1 = IX(1)
      X2 = IX(2)
      X3 = IX(3)
      X4 = IX(4)
      X5 = IX(5)
      I = I + 1
      IF ( I .GT. 2 ) I = 1
      GO TO (10,20),I
C
   10 CONTINUE
      AVVOL= X1/100.
C AVVOL = AVERAGE VOLUMN PER ACRE - CUFT.
      AVDBH= X2/100.
C ACDBH = AVERAGE DBH - INCHES
      AVHGT=X3
C AVHGT = AVERAGE TREE HEIGTH - FEET
      TRPAC=X4
C TRPAC = AVERAGE NUMBER TREES PER ACRE
      TRSPC=(43560./TRPAC)**.5
C TRSPC = AVERAGE TREE SPACING - FEET
      WRITE (6,1)
      WRITE(6,2) AVVOL,AVDBH,AVHGT,TRPAC,TRSPC
      RETURN
C
   20 CONTINUE
      NUMFB=1
C NUMFB = NUMBER OF FELLER-BUNCHERS
      ACCLM =  X2
C ACCLM ACCUMULATOR LIMIT SUM OF DBH
      FBTYP=X3
C  FBTYP  FELLER BUNCHER TYPE  0 = DROTT  1 = RUBBER-TIRED TYPE
      BUNLM = X4
C  BUNLM  BUNCH SIZE LIMIT
      IF(FBTYP.EQ.0)WRITE(6,3)NUMFB
      IF(FBTYP.EQ.1)WRITE(6,4)NUMFB
      IF (ACCLM .LT. 1.) WRITE(6,5)
      IF (ACCLM .GE. 1.) WRITE(6,6) ACCLM
```

```
      SUBROUTINE FELBN (IX)
      DIMENSION IX(5)
      DATA I/0/
      INTEGER FBACC,FBDIS,BNCOM
C
    1 FORMAT (1H1,4X,'F E L L E R - B U N C H E R   P R O D U C T',
     A' I O N   A N D   C O S T   S U M M A R Y',//,1H ,132('*'),////
     B//,1H,'I.      A.',F8.2,5X,'HOURS WORKED BY FELLER-BUNCHER(S)'
     1 ,' INCLUDING'//16X,F8.2,
     2 5X      'MINUTES OF PERSONAL BREAKS, ',//16X,F8.2,
     3   5X,   'MINUTES MECHANICAL DELAY, ',/  / 16X,F8.2,
     4 5X,     'MINUTES NON-MECHANICAL DELAY',
     C//,7X,'B.',I8,5X,'FELLER-BUNCHER, ',5X,
     D 'TRACKED TYPE-ROTATABLE BOOM WITH ACCUMULATOR SHEAR'///)
C
    2 FORMAT (1H1,4X,'F E L L E R - B U N C H E R   P R O D U C T',
     A' I O N   A N D   C O S T   S U M M A R Y',//,1H ,132('*'),////
     B//,1H,'I.      A.',F8.2,5X,'HOURS WORKED BY FELLER-BUNCHER'
     1 ,' INCLUDING'//16X,F8.2,
     2 5X,     'MINUTES OF PERSONAL BREAKS, ',//16X,F8.2,
     3   5X,   'MINUTES MECHANICAL DELAY, ',/  / 16X, F8.2,
     4 5X,     'MINUTES NON-MECHANICAL DELAY',
     C//,7X,'B.',I8,5X,'FELLER-BUNCHER, ',5X,
     D'RUBBER-TIRED TYPE.'///)
C
    3 FORMAT(1H,'II.     A.',I8,5X,'TOTAL ACCUMULATOR CYCLES COMPLETED',
     A' - ALL MACHINES.',//,16X,F8.2,5X,'AVERAGE NUMBER OF TREES PER',
     B' CYCLE.',//,16X,F8.2,5X,'AVERAGE VOLUME PER CYCLE - CU.FT.',/)
C
    4 FORMAT(1H,6X,'B.',I8,5X,'BUNCHES COMPLETED',//,
     A16X,F8.2,5X,'AVERAGE NUMBER OF TREES PER BUNCH.',/)
C
    5 FORMAT(1H,15X,F8.2,5X,'AVERAGE NUMBER OF CYCLES PER BUNCH.',/)
C
    6 FORMAT(1H,15X,F8.2,5X,'AVERAGE VOLUME PER BUNCH - CU.FT.',//,
     A7X,'C.',I8,5X,'TOTAL TREES FELLED.',//,7X,'D.',F8.1,5X,
     B'TOTAL VOLUME FELLED - CU.FT.',//,7X,'E.',
     CF8.2,5X,'TOTAL TONS FELLED',//,7X,'F.',I8,5X,
     D   'TOTAL DISTANCE TRAVELED - FEET',///)
C
    7 FORMAT(1H,'III.    A.',F8.2,5X,'AVERAGE NUMBER OF CYCLES PER',
     A' MACHINE HOUR.',/)
C
    8 FORMAT(1H,6X,'B.',F8.2,5X,'AVERAGE NUMBER OF BUNCHES COMPLETED',
     A' PER MACHINE HOUR.',//,7X,'C.',F8.2,5X,'AVERAGE NUMBER OF',
     B' TREES FELLED PER MACHINE HOUR.',//,7X,'D.',F8.2,5X,'AVERAGE',
     C' VOLUME FELLED PER MACHINE HOUR.',//,7X,'E.',F8.2,5X,'AVERAGE',
     D' NUMBER OF TONS FELLED PER MACHINE HOUR.',//,7X,'F.',F8.2,5X,
     E'AVERAGE DISTANCE TRAVELED PER MACHINE HOUR - FEET.',///)
C
C
   11 FORMAT(1H,'IV.     A.',F8.2,5X,'TOTAL GALLONS OF FUEL USED BY',
     A' THE FELLER-BUNCHER.',//,16X,F8.2,5X,'GALLONS PER HOUR.',//,16
     BX,F8.2,5X,'GALLONS PER TON.',//,16X,F8.2,5X,'GALLONS PER CUNIT.')
C
      X1 = IX(1)
      X2 = IX(2)
      X3 = IX(3)
      X4 = IX(4)
      X5 = IX(5)
      I = I+ 1
      IF (I .GT. 3 ) I = 1
      GO TO ( 10,20,30),I
   10 CONTINUE
      NUMFB = 1
C NUMFB =  NUMB. OF FELLER-BUNCHERS
      FBTYP = X2
C  FELLER-BUNCHER TYPE  0 = DROTT  1 = RUBBER-TIRED TYPE
C  BREAK AND DELAY TIMES IN MINUTES
      BREAK=X3/100
      DELAY=X4/100
      DELNM=X5/100
      RETURN
   20 CONTINUE
```

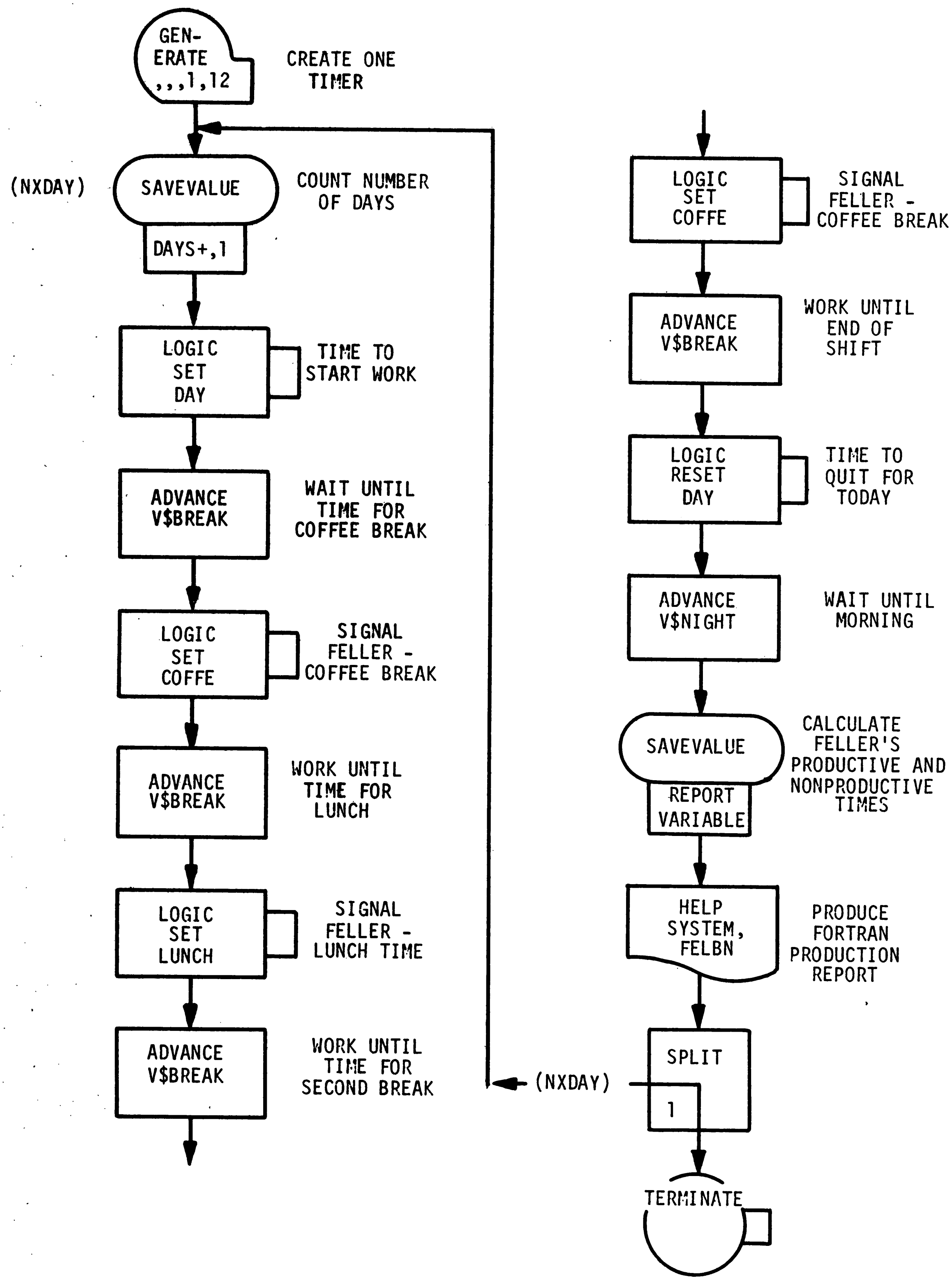
```
      NTREE =  X1
      FBVOL = X2/100.
C FBVOL =    VOL. FELLED ALL MACHINES
      FBCNT = FBVOL/100.
C  FBCNT  FELLER-BUNCHER VOL. IN CUNITS.
      BNCOM = X3
C BNCOM =  BUNCHES COMPLETED
      FBHR = X4/100.
      FBDIS =  X5
C FBDIS =   DIST. TRAV. ALL MACHINES
      RETURN
   30 CONTINUE
      FBACC = X1
C  FBACC  NUMBER OF ACCUMULATOR COMPLETED CYCLES.
      XDEN = X2
C  POUNDS OF WOOD PER CUBIC FOOT.
      FBTNS = X3*XDEN/200000
      FBGPH = X4/10
C  FELLER-BUNCHER TOTAL GALLONS USED
C  FELLER-BUNCHER VOL. IN TONS
C
      IF( FBTYP.EQ.0 )WRITE(6,1)FBHR,BREAK,DELAY,DELNM,NUMFB
      IF( FBTYP.EQ.1 )WRITE(6,2)FBHR,BREAK,DELAY,DELNM,NUMFB
C
      FBTPC = NTREE*1./FBACC
C  FBTPC  TREES PER CYCLE
      FBVPC = FBVOL/FBACC
C  FBVPC  VOLUME PER CYCLE
      WRITE(6,3)FBACC,FBTPC,FBVPC
C
      FBTPB =  NTREE*1./BNCOM
C FBTPB =  AVE. TREES PER COMPLETED BUNCH.
      WRITE(6,4)BNCOM,FBTPB
C
      FBCPB = FBACC*1./BNCOM
      WRITE(6,5)FBCPB
C
      FBVPB = FBVOL/BNCOM
C FBVPB =  AVE. VOL. PER BUNCH
      WRITE  (6 ,6) FBVPB,NTREE,FBVOL,FBTNS,FBDIS
C
      CYCHR = FBACC/FBHR
      WRITE(6,7)CYCHR
C
      FBBMH = BNCOM/FBHR
C FBBMH = AVE. BUNCHES PER MACHINE HOUR
      FBTMH = NTREE/FBHR
C FBTMH = TREES FELLED PER MACHINE HOUR
      FBVMH = FBVOL/ FBHR
C FBVMH = VOL. FELLED PER MACHINE HOUR
      FBATH = FBTNS/FBHR
C  FBATH  AVERAGE TONS PER HOUR
      FBDMH = FBDIS/FBHR
C FBDMH = DIST. TRAV. PER MACHINE HOUR
      WRITE  (6 ,8) FBBMH,FBTMH,FBVMH,FBATH,FBDMH
C
C  FELLER-BUNCHER GALLONS/HOUR
      FBGPT = FBGPH/FBATH
C  FELLER-BUNCHER GALLONS PER TON
      FBGPC = FBGPH/(FBVMH/100)
C  FELLER-BUNCHER GALLONS PER CUNIT
      FBTGU = FBGPH*FBHR
      WRITE(6,11)FBTGU,FBGPH,FBGPT,FBGPC
      RETURN
      END
```

APPENDIX C

COMPLETE FLOW CHARTS

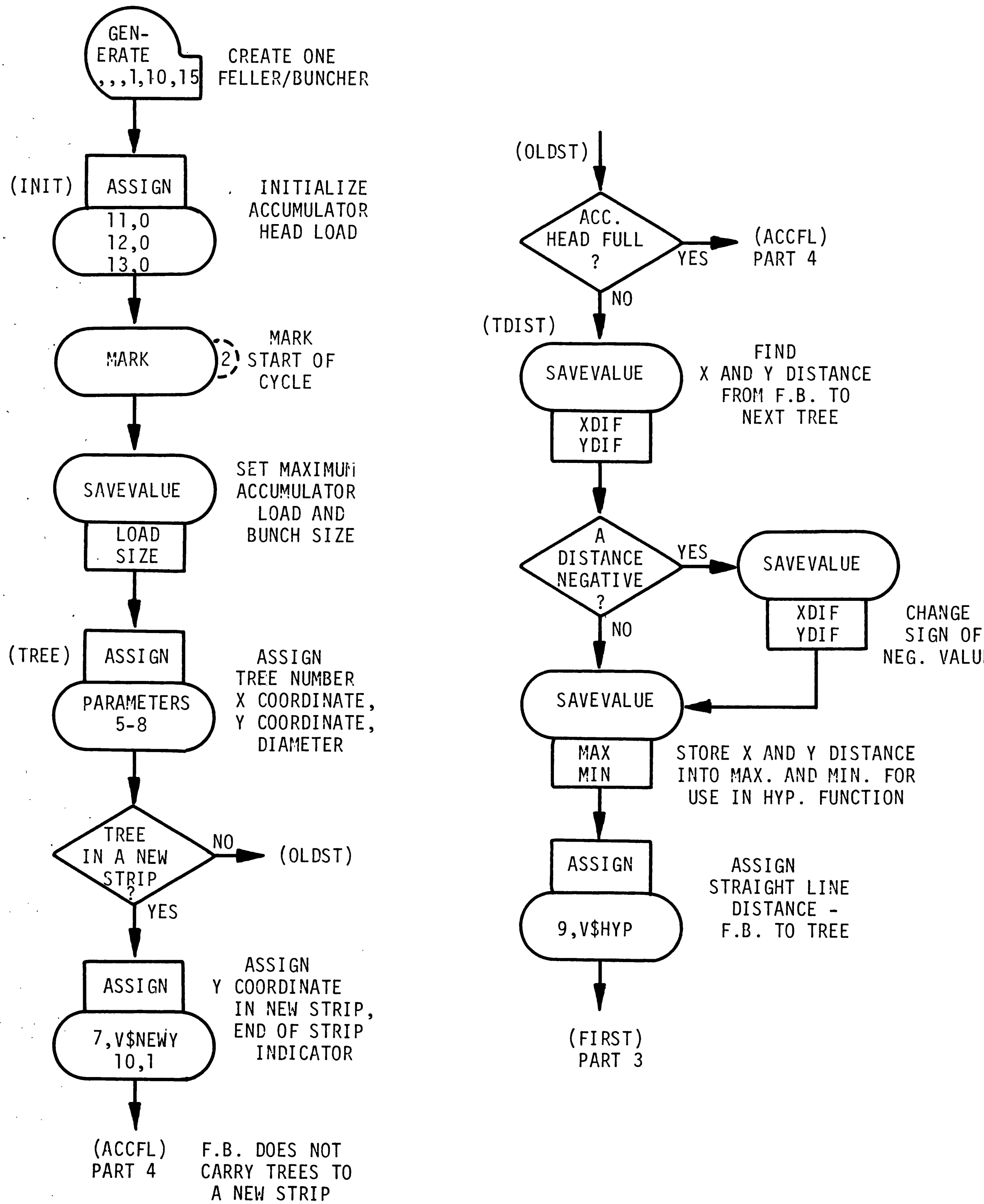
COMPLETE FLOW CHARTS - PART 1 OF 6

TIMER SEGMENT



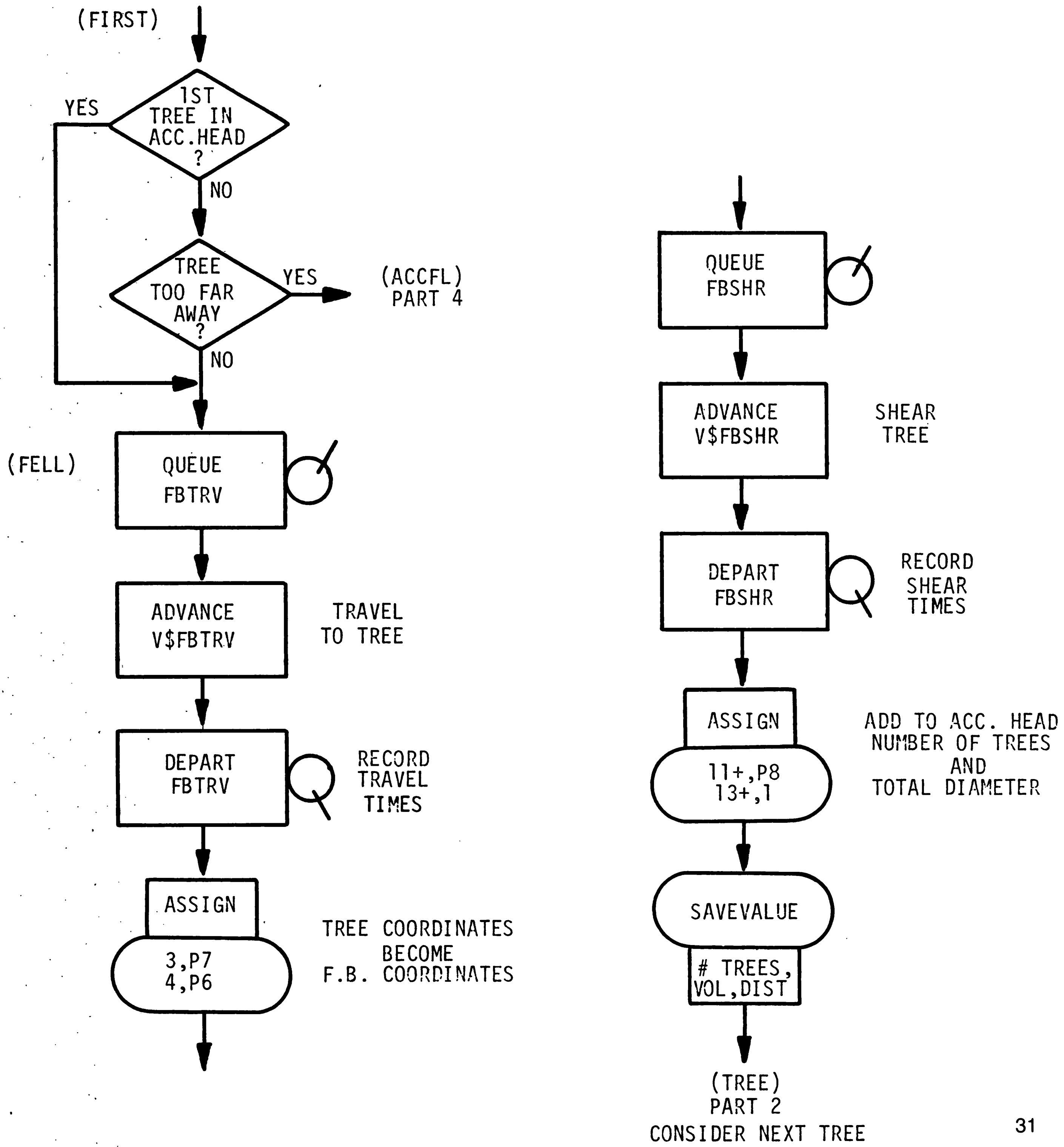
COMPLETE FLOW CHARTS - PART 2 OF 6

RUBBER TIRED FELLER/BUNCHER SEGMENT



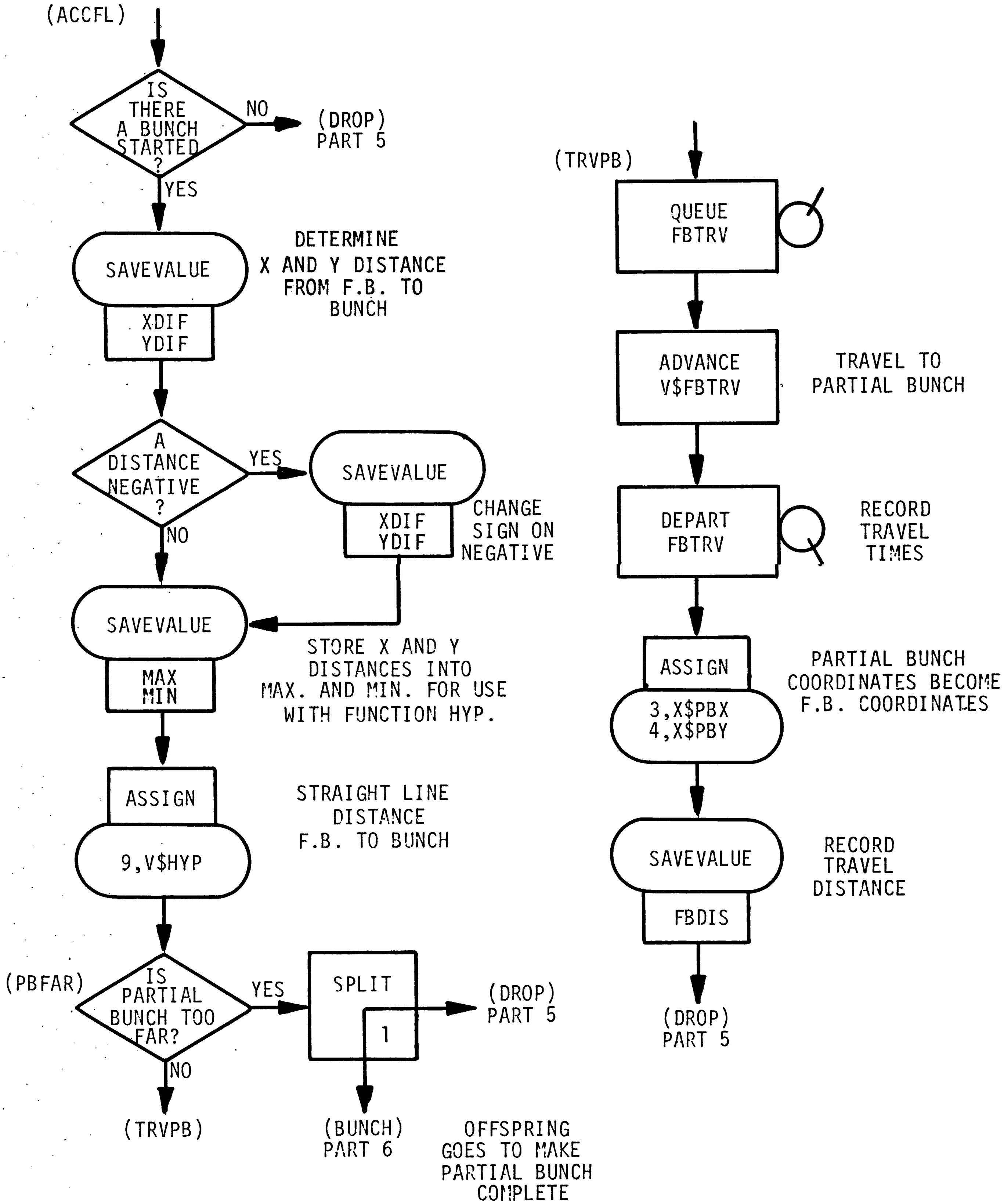
COMPLETE FLOW CHARTS - PART 3 OF 6

RUBBER TIRED FELLER/BUNCHER SEGMENT

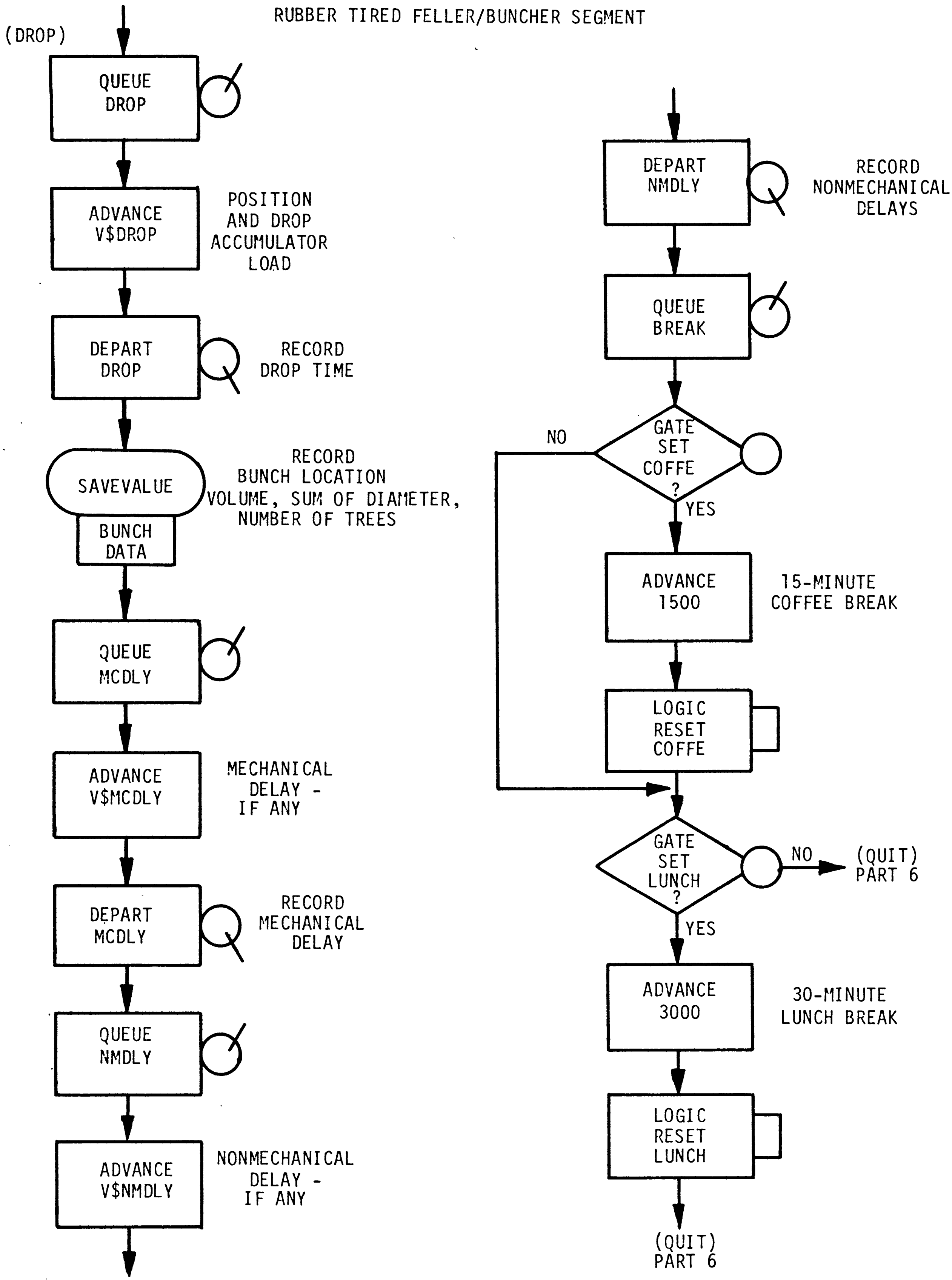


COMPLETE FLOW CHARTS - PART 4 OF 6

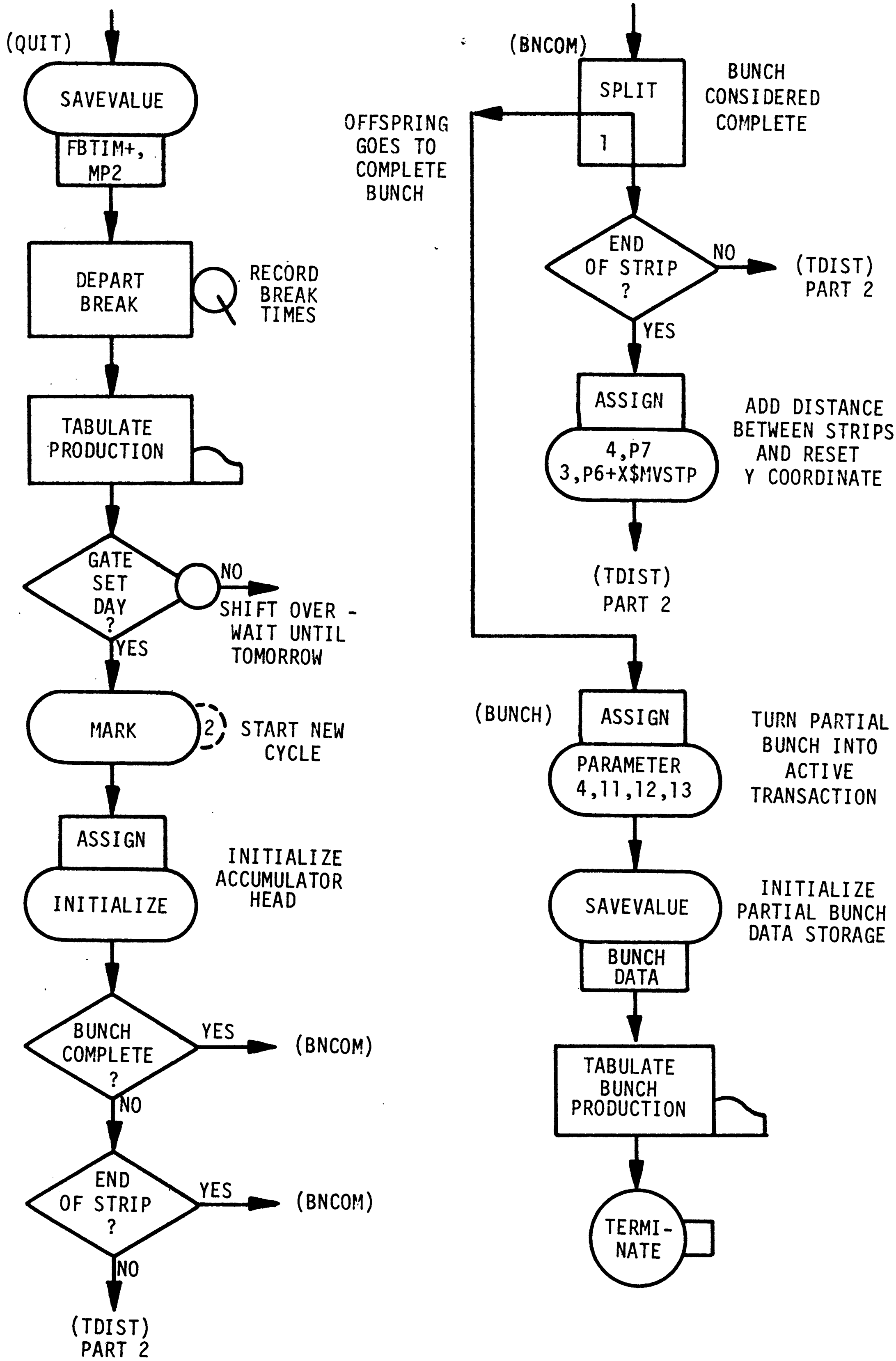
RUBBER TIRED FELLER/BUNCHER SEGMENT



RUBBER TIRED FELLER/BUNCHER SEGMENT



RUBBER TIRED FELLER/BUNCHER SEGMENT



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