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A program and documentation for simulation of a **tracked feller/buncher**

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A PROGRAM AND DOCUMENTATION FOR SIMULATION OF A TRACKED 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 machine components for improving equipment design to overviews of major systems for estimating large-scale changes in productivity. Forestry Sciences Laboratory personnel at Houghton have been involved for the past several years in developing harvesting simulators for use in forest engineering research (Bradley *et al.* 1976, Bradley and Winsauer 1976, 1978, U.S. Department of Agriculture Forest Service 1978).

The purpose of this paper is to present a computer model and documentation for a tracked feller/buncher (fig. 1). The model was developed to provide a detailed study of this machine's operation in the woods during harvesting operations. It allows the user to identify productive and unproductive conditions, to experiment with ways of increasing machine efficiency, to predict the effects of system changes, and to determine harvest costs for various types of stands and conditions.

THE EQUIPMENT STUDIED

The feller/buncher is a tracked vehicle with a shear mounted on the end of a rotatable hydraulic boom. The shear head can either sever and bunch single stems or accumulate several stems at once. The boom enables the feller/buncher to shear trees up to the boom's maximum reach while maintaining a fairly straight path through the woods; cutting a strip for thinning or in working the face of a clearcut stand.

MODEL OBJECTIVES

The model was designed to study the productivity and operation of the feller/buncher in the woods. Input required includes data on the machine's operating characteristics, the stand itself, and the type of harvest to be carried out.

Model output includes productivity figures such as number of trees, weight and volume harvested per hour or load, number of total cycles (accumulator head loads), number of trees per cycle, total distance traveled, and skid bunches completed.

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

Figure 1.—*Tracked feller/buncher.*

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 of a group of specific GPSS block types, which then become the GPSS program. A basic understanding of the GPSS language allows the user to accurately interpret or modify the simulation.

Most versions of GPSS have a standard output format that concisely presents the data. The FORTRAN subroutines are used to present important output values in an organized, labeled form.

MODEL ASSUMPTIONS

The basic time unit used in the model is a "centiminute"— that is, 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 0.01 cu. ft.

The feller/buncher is assumed to operate 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 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. The machine has an accumulating shear. (The model can easily be changed to single-head shear).
2. The feller/buncher travels in a relatively straight row, either along the edge of a clearcut or down a thinning strip, harvesting all trees within reach that are scheduled for cutting. At the end of the strip, it travels through the woods to the next strip, then returns along that strip toward the landing (fig. 2).
3. If there are no more trees within the feller's reach, the bunch it was working on is considered complete and the feller must move forward— it does not back up.
4. If a bunch is not started at a given location (only one accumulator head load has been cut), the feller will carry the trees in the shear head to the next location. (Exception: if the end of the row (strip) has been reached, the feller will drop the load there before traveling to the next strip.
5. The feller/buncher can quit for the day or stop for a break only after completing a bunch for the skidder.
6. Mechanical and nonmechanical delays are incorporated into the model. For ease of programming, they are assumed to occur after the feller/buncher drops the current load of trees.

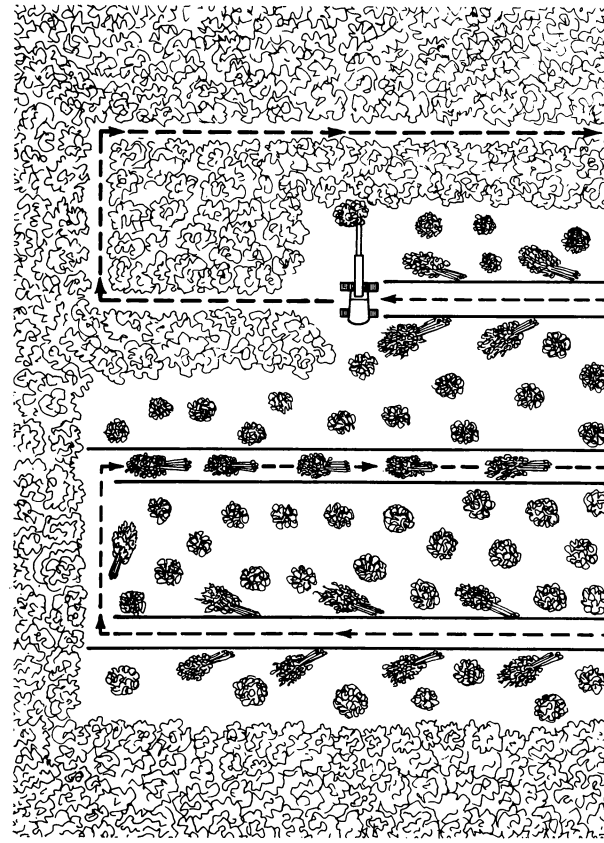

Figure 2.—*Feller/buncher travel pattern.*

MODEL DESCRIPTION

The model consists of two GPSS segments: (1. **Timer segment**, 2. **Feller/buncher segment**) and two FORTRAN subroutines for easily read output. A complete variable list, program listing, and flow charts are contained in Appendixes A, B, and C.

The **Timer segment** (fig. 3) controls the daily schedule, keeps track of the days worked, and sends information to the subroutines. The **Timer** signals the start of the day, the rest breaks and the lunch break (two 15-minute breaks a day and ½ hour lunch break are assumed), and the end of the workday. The **Timer** then completes the 24-hour day and produces a 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 has been simulated, the model shuts off. Otherwise the start of another work day is signaled and the process continues.

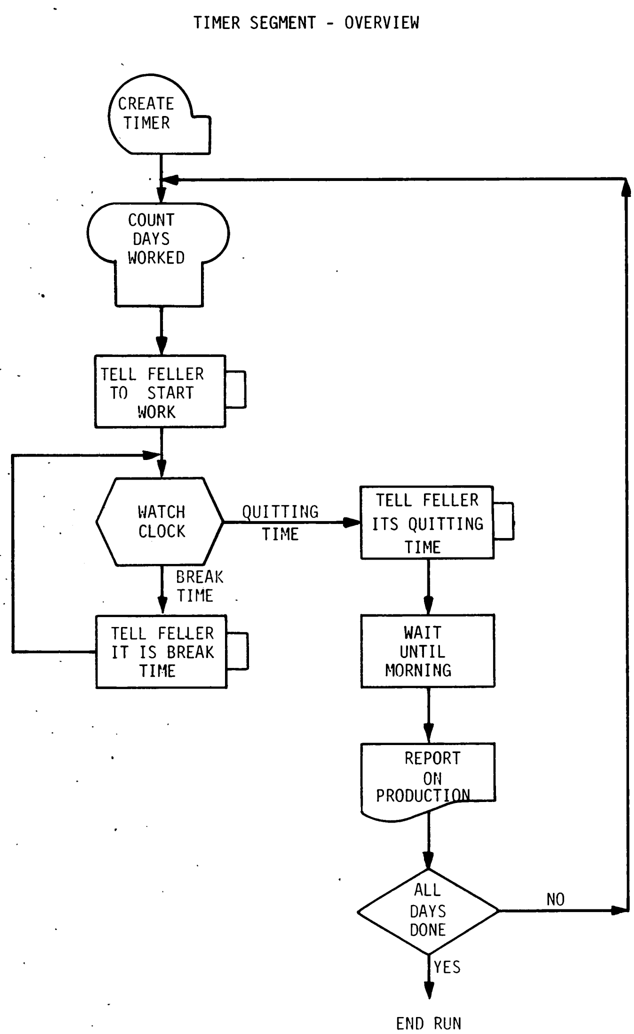

Figure 3.—*Overview of the* **timer segment.**

The **Feller/buncher segment** (fig. 4) simulates a tracked feller/buncher with a boom-mounted shear. This boom enables the machine to remain at a harvesting station while it shears and bunches trees within a radius of 20 feet, (the radius depends on the stand and the harvesting treatment as well as on the physical reach of the boom).

The feller is assumed to move into the woods, cut one or more trees, then drop them to one side to form a bunch. After all the trees to be cut at that location are processed, the feller moves to the next set of trees and repeats the process.

INPUT DATA

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

Most of the data required by this program are needed in the form of VARIABLES. VARIABLES can be defined in terms of the other input types (Appendix D), thus allowing the user flexibility of input data without card shuffling in the main body of the program. For example, a shear-time change from a constant (SAVEVALUE) to a distribution (FUNCTION) can be accomplished by simply redefining the shear-time VARIABLE.

The major exception to this convention is the use of SAVEVALUES (constants) for the summary values (average stand d.b.h., average tree height, etc.) that are used simply for output information.

DATA REQUIRED BY MODEL

Four types of data describing the equipment and harvesting operation must be supplied to run the simulation: (1) stand data (table 2); (2) machine data dependent on stand conditions (table 3); (3) machine data independent of stand conditions (table 4); and (4) simulation run control data (table 5).

The sample output presented in this paper resulted from running the simulation with the input data in tables 2-5. These data were gathered from time studies carried out during actual logging operations. Although the data in the tables may not represent the operating characteristics of the feller/buncher under all conditions, they do present a reasonably accurate picture of its performance in a stand of this type (table 2).

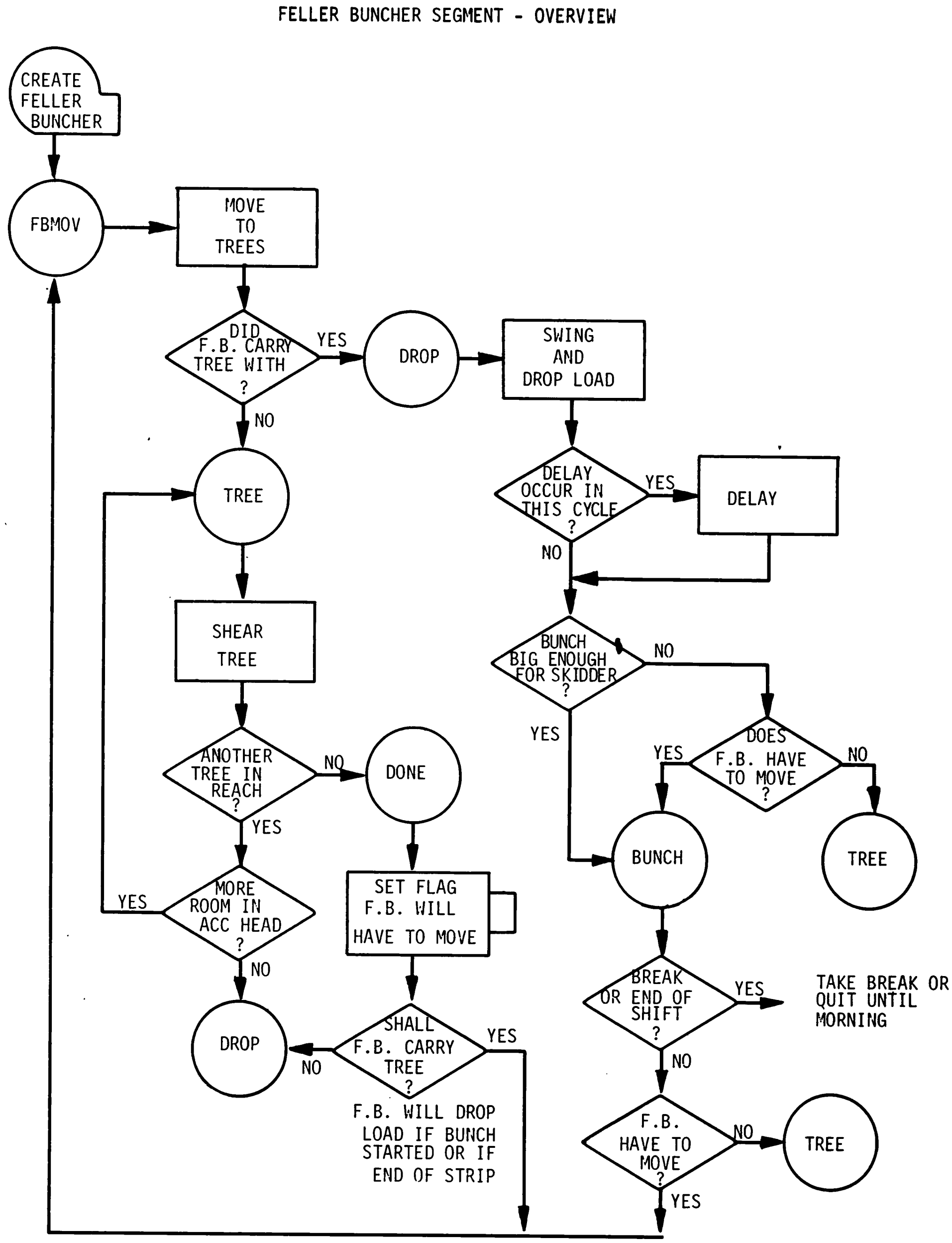

Figure 4.—*Overview of the* **feller/buncher segment.**

SIMULATION OUTPUT

The simulation run produces two pages of labeled output for each day of the run (figs. 5 and 6). These pages contain a summary of the stand data and a cumulative productivity report. Additional output, with complete run details, is produced at the end of the run by the GPSS processor.

The first page of standard output (fig. 7) 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 statistics 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

Table 1.—*GPSS Data input forms*

<table>
<tr><th>Input data type</th><th>Input form in GPSS</th><th>Example</th></tr>
<tr><td>Simple averages
or constants</td><td>Initialized SAVEVALUES</td><td>Ave. d.b.h. = 6 in.</td></tr>
<tr><td>Range of values</td><td>Initialized SAVEVALUES
for mean and one-half
width of interval</td><td>Shear time = 10 to 14 centi-min.
= 12 ± 2 centi-min.</td></tr>
<tr><td>Equations</td><td>VARIABLES</td><td>Vol. = .13 d.b.h.^{2} – .28</td></tr>
<tr><td>Frequency
distributions</td><td>FUNCTIONS</td><td><table><tr><td>D.b.h.(in.)</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td></tr><tr><td>percent trees</td><td>23</td><td>25</td><td>30</td><td>15</td><td>5</td></tr></table></td></tr>
<tr><td>Mean and variance for
a standard distribution
such as normal, Poisson
Exponential, etc.</td><td>SAVEVALUES and
FUNCTIONS for the
distribution</td><td>Wait time is normally
distributed with
mean = 10
variance = 9</td></tr>
</table>

Table 2.—*Stand data*

<table>
<tr><th>Data required</th><th>Case study</th><th>Form required
by program</th><th>Name</th></tr>
<tr><td>Ave. stand diameter</td><td>5.5 in. d.b.h.</td><td>SAVEVALUE</td><td>X$AVDBH</td></tr>
<tr><td>Ave. stand volume</td><td>3,450 cu. ft./acre</td><td>SAVEVALUE</td><td>X$AVVOL</td></tr>
<tr><td>Ave. tree height</td><td>43 ft.</td><td>SAVEVALUE</td><td>X$AVHGT</td></tr>
<tr><td>Ave. trees/acre</td><td>844 trees/acre</td><td>SAVEVALUE</td><td>X$TRPAC</td></tr>
<tr><td>Strip length</td><td>725 ft.</td><td>VARIABLE</td><td>V$STPLN</td></tr>
<tr><td>Distance between strips</td><td>35 ft.</td><td>SAVEVALUE</td><td>X$MVSTP</td></tr>
<tr><td>Wood density</td><td>55 lb./cu. ft.</td><td>SAVEVALUE</td><td>X$LBCFT</td></tr>
<tr><td>Hours in daily work
shift</td><td>8 hrs.</td><td>SAVEVALUE</td><td>X$WKDAY</td></tr>
<tr><td>Actual tree diameters</td><td>Diameter distribution:<table><tr><td>D.b.h.(in.)</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td></tr><tr><td>percent trees</td><td>5</td><td>23</td><td>30</td><td>24</td><td>14</td><td>3</td><td>1</td></tr></table></td><td>VARIABLE</td><td>V$TDIA</td></tr>
<tr><td>Tree volume</td><td>Volume of trees (cu. ft.):
Volume = –0.283 + .0031 (DBH^2) tree ht.
= –0.283 + 0.133 (DBH^2)
assuming tree ht. = 43 ft.</td><td>VARIABLE</td><td>V$TVOL</td></tr>
</table>

cannot be used. For example:

FBHR = 4020 = feller hours × 100
FBTRE = 6663 trees cut
6663/40.2 = 165.75 trees/hr.

Additional details of the woods operations are provided by the output tables (figs. 8-10). The cycle time table (cycle time starts after the feller/buncher drops one load and ends when it drops the next) shows there were 2,667 cycles with an average cycle time of 79 centi-minutes. Of all cycles, 209 cycles or 7.8 percent took between 100 and 125 centi-minutes.

It should be noted that all of the output is based on random processes in the model. Therefore, the output data are themselves random, only a sample of what could happen. If the model is run again with different random numbers, the results will be different. An average over several days or several runs is the best estimate of an actual system.

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

Data required	Case study							Form required by program	Name
Number of trees within reach of accumulator head from a given location	Distribution: trees in head							VARIABLE	V$REACH
	Number of trees	2-4	4-6	6-8	10-12	12-16	16-18		
	percent time	3	7	10	20	20	8		
	Number of trees	18-20	20-22	22-24	24-26	26-30	30-38		
	percent time	7	6	5	4	5	5		
Distance feller must move to be well positioned to cut next set of trees	Distribution: feller travel							VARIABLE	V$FBMOV
	ft.	0-5	5-10	10-25	25-35	35-50			
	percent time	10	15	30	20	10			
	ft.	50-60	60-90	90-120					
	percent time	5	5	5					

```
                    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.

   3450.00 CU FT. AVERAGE VOLUME PER ACRE.
      5.50 INCHES, AVERAGE DBH.
     43.00 FEET, AVERAGE TREE HEIGHT.
    884.00 AVERAGE NUMBER OF TREES PER ACRE.
      7.02 FEET, AVERAGE TREE SPACING.

II. SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ANALYST.
 A.  FELLER-BUNCHER,                  1 MACHINE     TRACKED TYPE-ROTATABLE BOOM WITH ACCUMULATOR SHEAR
      MACHINE LIMITATIONS
        THE ACCUMULATOR-SHEAR WILL TRY TO OBTAIN A LOAD OF UP TO   4.0 TREES
      BUNCH LIMITATIONS DICTATED BY SKIDDER CAPACITY:
        THE FELLER-BUNCHERS TRY TO ACHIEVE SKIDDER BUNCHES WITH A TOTAL SUM OF DIAMETERS EQUAL TO 120.0 INCHES
```

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

KNOWN GPSS SYSTEMS DIFFERENCES

The program listed in Appendix B is operational on a UNIVAC 1110 under an implementation of GPSS called GPSS-X8, which can be obtained from 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 front of the deck for most other GPSS processors.

Job control cards— These are unique to each com-

Table 4.—*Machine data*

Data required	Case study								Form required by program	Name
Travel time (based on distance)	Travel speed: mean 49 ft./min. s.d. 19 ft./min.								VARIABLE	V$FBTRAV
Shear time per tree	Distribution: shear time								VARIABLE	V$FBSHR
	time (centi-min.)	0-10	10-20	20-30	30-40					
	percent of cuts	29	39	21	8					
	time (centi-min.)	40-50	50-60	60-70	70-90					
	percent of cuts	1	1	.5	.5					
Drop and bunch time per load	Distribution: drop and bunch time								VARIABLE	V$FBDRP
	time (centi-min.)	1-10	10-20	20-30	30-40					
	percent of cuts	3	67	15	3					
	time (centi-min.)	40-50	50-60	60-70						
	percent of cuts	1	.5	.5						
Number of trees per accumulator load	Distribution: trees/accumulator head load								VARIABLE	V$ACCLM
	number of trees	1	2	3	4	5				
	percent loads	22	23	28	17	10				
Maximum size of skidder bunch FB tries to create (total sum of d.b.h.)	120 in.								VARIABLE	V$BUNLM
Gal./hr. fuel used	5.5 gal./hr.								SAVEVALUE	X$FBGPH
Length of nonmechanical delays/cycle (including cycles with zero delay)	Distribution of nonmechanical delays (min.)								VARIABLE	V$NMDLY
	length of delay	0	.15	.25	.35	.40	.50	.75		
	percent of cycles	98.5	.2	.2	.2	.1	.1	.3		
	length of delay	.80	1.0	2.0	3.0	4.0	5.0			
	percent of cycles	.3	.3	.1	.1	.1	.1			
Length of mechanical delays/cycle (including cycles with zero delay)	Distribution of mechanical delays (min.)								VARIABLE	V$MCDLY
	length of delay	0	.5	1.0	1.5	2.0	2.5	5.0		
	percent of cycle	99	.1	.1	.1	.1	.1	.1		
	length of delay	10.0	20.0	30.0	40.0					
	percent of cycle	.1	.1	.1	.1					

puter lab, and must be obtained locally.

HELP BLOCKS—In GPSS-X8, HELP blocks (lines 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; i.e., the subroutine cannot pass arguments back to GPSS. Some versions of GPSS do not allow HELP blocks. In such cases the program can be run without lines 48 to 80; these data can instead be obtained from the standard output. If some form of HELP blocks are allowed, their format and the subroutines may have to be changed. See the GPSS manual for your computer installation.

SENSITIVITY

Table 6 presents the results of a preliminary study of the model's sensitivity. The model was run to fit

Table 5.—*Simulation run control*

Data required	Case study	Form required by program
Random number generators	Random number use 1—used by GPSS scheduler 2—Shear time and drop time distribution 3—trees in reach and distance to move distributions 4—d.b.h. distribution 5—not used 6—delays distribution	RMULT CARD
Number of days	5 days	START CARD
Standard output	every 5th day	

```
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.   40.20    HOURS WORKED BY FELLER-BUNCHER(S) INCLUDING
              298.22    MINUTES OF PERSONAL BREAKS,
              213.36    MINUTES MECHANICAL DELAY,
               26.67    MINUTES NON-MECHANICAL DELAY
     B.       1    FELLER-BUNCHER,    TRACKED TYPE-ROTATABLE BOOM WITH ACCUMULATOR SHEAR

II.  A.    2667    TOTAL ACCUMULATOR CYCLES COMPLETED - ALL MACHINES.
                2.50    AVERAGE NUMBER OF TREES PER CYCLE.
                9.13    AVERAGE VOLUME PER CYCLE - CU.FT.
     B.     481    BUNCHES COMPLETED
               13.85    AVERAGE NUMBER OF TREES PER BUNCH.
                5.54    AVERAGE NUMBER OF CYCLES PER BUNCH.
               50.63    AVERAGE VOLUME PER BUNCH - CU.FT.
     C.    6663    TOTAL TREES FELLED.
     D. 24354.2    TOTAL VOLUME FELLED - CU.FT.
     E.  669.74    TOTAL TONS FELLED
     F.   13934    TOTAL DISTANCE TRAVELED - FEET

III. A.   66.34    AVERAGE NUMBER OF CYCLES PER MACHINE HOUR.
     B.   11.97    AVERAGE NUMBER OF BUNCHES COMPLETED PER MACHINE HOUR.
     C.  165.75    AVERAGE NUMBER OF TREES FELLED PER MACHINE HOUR.
     D.  605.83    AVERAGE VOLUME FELLED PER MACHINE HOUR.
     E.   16.66    AVERAGE NUMBER OF TONS FELLED PER MACHINE HOUR.
     F.  346.62    AVERAGE DISTANCE TRAVELED PER MACHINE HOUR - FEET.

IV.  A.  221.10    TOTAL GALLONS OF FUEL USED BY THE FELLER-BUNCHER.
                5.50    GALLONS PER HOUR.
                 .33    GALLONS PER TON.
                 .91    GALLONS PER CUNIT.
```

Figure 6.—*Simulation output: productivity.*

*** GPSS/X8 NORMAL COMPLETION OF SIMULATION RUN ***

RELATIVE CLOCK: 720001 ABSOLUTE CLOCK: 720001

TRANS COUNTS:

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, 5	OUTPT	0, 5	ACCFB	0, 1	25	0, 1
INIT	0, 1	27	0, 1	28	0, 1	29	0, 1	30	0, 1
31	0, 1	32	0, 1	FBMOV	0, 458	34	0, 458	35	0, 458
36	0, 458	37	0, 458	38	0, 458	39	0, 458	40	0, 458
41	0, 458	42	0, 458	TREE	0, 6663	44	0, 6663	45	0, 6663
46	0, 6663	47	0, 6663	48	0, 6663	49	0, 6663	50	0, 6663
51	0, 6663	52	0, 6663	53	0, 6663	54	0, 6205	55	0, 2209
DONE	0, 458	57	0, 458	58	0, 441	59	0, 29	STRIP	0, 17
DROP	0, 2667	62	0, 2667	63	0, 2667	64	0, 2667	65	0, 2667
66	0, 2667	67	0, 2667	68	0, 2667	69	0, 2667	70	0, 2667
71	0, 2667	72	0, 2667	73	0, 2667	74	0, 2667	75	0, 2667
76	0, 2667	77	0, 2667	78	0, 2667	79	0, 2667	80	0, 2667
81	0, 2667	82	0, 2667	83	0, 2667	84	0, 2667	85	0, 2667
86	0, 2667	87	0, 2667	88	0, 2596	BUNCH	0, 481	90	0, 481
91	0, 481	92	0, 481	93	0, 481	94	0, 481	95	0, 481
96	0, 481	97	0, 481	98	0, 481	99	0, 481	100	0, 481
101	0, 481	102	0, 10	103	0, 10	NOBRK	0, 481	105	0, 5
106	0, 5	QUIT	0, 481	108	1, 481	109	0, 480	110	0, 480
111	0, 480	112	0, 428	113	0, 17	114	0, 17	115	0, 17
116	0, 17	117	0, 17						

CURRENT EVENTS CHAIN

TRANS	BDT	BLK	PR	NBA	MARKTIME	SET	SDIP	PARAMETERS											
6	720001	23	12	24	1	1		0	0	0	0	0	0	0	0	0	0	0	0
7	0	22	12	2	1	1		0	0	0	0	0	0	0	0	0	0	0	0
2	624285	108	10	109	1	0	11	0	624285	637	572	6663	3	120	7	69	0	0	0
								0	0	0	0	0	0	0	0	0	0	0	0

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	481	466	96.9	62.37	2000.00	0	0
MCDLY	1	.03	2667	2644	99.1	8.49	984.78	0	0
NMDLY	1	.00	2667	2636	98.8	1.20	103.55	0	0
FBTRV	1	.04	458	9	2.0	70.95	72.37	0	0
FBSHR	1	.15	6663	218	3.3	16.43	16.98	0	0
DROP	1	.06	2667	21	.7	16.27	16.40	0	0

SAVE VALUES

SAVEX

NR	VALUE	NR	VALUE	NR	VALUE	NR	VALUE	NR	VALUE
WKDAY	8	DAYS	5	FBHR	4020	BRKTM	29822	DELYA	21336
DELNM	2667	FBTIM	241203	AVVOL	345000	AVDBH	550	AVHGT	43
TRPAC	884	NUMFB	0	ACLM1	0	FBTYP	0	BNLM1	120
FBTRE	6663	FBVOL	2435417	BNCOM	481	FBDIS	13934	FBACC	2667
LBCFT	55	FBGPH	55	LASTB	572	STPLN	725	BNDTA	0
BNTRE	0	BNDIF	31	BNLOC	572	BNVOL	0	STRIP	18
FBOUT	100	DBH	7	FTRV1	49	FTRV2	19	MVSTP	35
ACCLM1	4	37	0	38	0	39	0	40	0

Figure 7.—*Simulation output: standard GPSS form.*

actual data as closely as possible. Then one parameter at a time was varied and the effect on productivity noted.

These sensitivity figures can be used (1) to give some indication of the accuracy required for the input data (the greater the sensitivity the more accurately that parameter should be specified), and (2) to give an indication of what factors should be further examined for their impact on the machine's productivity.

It should be noted that even parameters which did not show major changes in productivity at the levels of change examined could have larger effects when changed to a greater degree or when combined with other changes. In all cases, the better the input information, the more accurate the output data will be.

CONCLUSION

With the proper choice of input variables, the simulation model can be used to study productivity of feller/ bunchers under a variety of stand or harvesting conditions. It is possible to study the effects of a change in just one parameter or the effects of many changes at the same time. This model can also be combined with a model of skidding and chipping operations to provide productivity information for whole-tree systems.

Perhaps the greatest value of a GPSS model is the ease by which it can be modified to suit the exact requirements of a harvesting system. Although this requires some knowledge of GPSS, it makes simulation an extremely valuable tool.

CYCLE TIME (CENTI-MINUTES)

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
FBTIM	2667	79.19	167.70	211203.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
25	226	8.47	8.5	91.5	.31	-.32
50	837	31.38	39.9	60.1	.63	-.17
75	716	26.85	66.7	33.3	.94	-.02
100	416	15.60	82.3	17.7	1.26	.12
125	209	7.84	90.1	9.9	1.58	.27
150	99	3.71	93.9	6.1	1.89	.42
175	37	1.39	95.2	4.8	2.21	.57
200	31	1.16	96.4	3.6	2.53	.72
225	25	.93	97.3	2.7	2.84	.86
250	20	.75	98.1	1.9	3.16	1.02
275	13	.48	98.6	1.4	3.47	1.17
300	9	.33	98.9	1.1	3.79	1.32
325	5	.18	99.1	.9	4.10	1.47
375	2	.07	99.2	.8	4.74	1.76
400	1	.03	99.2	.7	5.05	1.91
425	2	.07	99.3	.7	5.37	2.06
450	2	.07	99.4	.6	5.68	2.21
475	2	.07	99.4	.5	6.00	2.36
550	4	.15	99.6	.4	6.95	2.81
575	1	.03	99.6	.3	7.26	2.96
600	1	.03	99.7	.3	7.58	3.11
OVERFLOW	9	.33	100.0	.0		

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

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
ACCVL	2667	913.17	538.03	2435417.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
500	767	28.76	28.8	71.2	.54	-.76
1000	861	32.28	61.0	39.0	1.10	.16
1500	626	23.47	84.5	15.5	1.64	1.09
2000	311	11.66	96.2	3.8	2.19	2.02
2500	87	3.26	99.4	.5	2.74	2.95
3000	15	.56	100.0	.0	3.29	3.88

Figure 8.—*Simulation output: productivity tables (1,*

NUMBER OF TREES PER ACCUMULATOR HEAD LOAD

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
ACCTR	2667	2.50	1.22	6663.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1	706	26.47	26.5	73.5	.40	-1.22
2	685	25.68	52.2	47.8	.80	-.40
3	714	26.77	78.9	21.1	1.20	.41
4	365	13.69	92.6	7.4	1.60	1.23
5	197	7.39	100.0	.0	2.00	2.05

NUMBER OF TREES PER SKIDDER BUNCH

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
BTREE	481	13.85	6.37	6663.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
2	2	.41	.4	99.6	.14	-1.86
3	10	2.08	2.5	97.5	.21	-1.70
4	16	3.33	5.8	94.2	.28	-1.55
5	15	3.12	8.9	91.1	.36	-1.39
6	27	5.61	14.6	85.4	.43	-1.23
7	24	4.99	19.5	80.5	.50	-1.08
8	23	4.78	24.3	75.7	.57	-.91
9	25	5.20	29.5	70.5	.65	-.76
10	25	5.20	34.7	65.3	.72	-.60
11	20	4.16	38.9	61.1	.79	-.44
12	28	5.82	44.7	55.3	.86	-.29
13	37	7.69	52.4	47.6	.93	-.13
14	25	5.20	57.6	42.4	1.01	.02
15	18	3.74	61.3	38.7	1.08	.18
16	23	4.78	66.1	33.9	1.16	.33
17	18	3.74	69.9	30.1	1.23	.49
18	16	3.33	73.2	26.8	1.30	.65
19	16	3.33	76.5	23.5	1.37	.80
20	18	3.74	80.2	19.8	1.44	.96
21	16	3.33	83.6	16.4	1.52	1.12
22	16	3.33	86.9	13.1	1.59	1.28
23	21	4.37	91.3	8.7	1.66	1.44
24	18	3.74	95.0	5.0	1.73	1.59
OVERFLOW	24	4.99	100.0	.0		

Figure 9.—*Simulation output: productivity tables (II).*

DISTANCES (FT) BETWEEN CONSECUTIVE BUNCHES

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
BDIF	481	25.93	27.60	12474.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	58	12.06	12.1	87.9	0.00	-.94
5	54	11.23	23.3	76.7	.19	-.75
10	55	11.43	34.7	65.3	.38	-.57
15	37	7.69	42.4	57.6	.57	-.39
20	51	10.60	53.0	47.0	.77	-.21
25	47	9.77	62.8	37.2	.96	-.03
30	44	9.15	71.9	28.1	1.16	.14
35	26	5.41	77.3	22.7	1.35	.32
40	9	1.87	79.2	20.8	1.54	.51
45	14	2.91	82.1	17.9	1.74	.69
50	17	3.53	85.7	14.3	1.93	.87
55	9	1.87	87.5	12.5	2.12	1.05
60	11	2.29	89.8	10.2	2.31	1.23
65	6	1.25	91.1	8.9	2.51	1.42
70	2	.41	91.5	8.5	2.70	1.60
OVERFLOW	41	8.52	100.0	.0		

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

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
BVOL	481	5063.24	2341.80	2435417.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1000	8	1.66	1.7	98.3	.19	-1.74
1500	19	3.95	5.6	94.4	.29	-1.52
2000	18	3.74	9.4	90.6	.39	-1.31
2500	29	6.03	15.4	84.6	.49	-1.09
3000	33	6.86	22.2	77.8	.59	-.88
3500	38	7.90	30.1	69.9	.69	-.66
4000	30	6.24	36.4	63.6	.79	-.45
4500	41	8.52	44.9	55.1	.88	-.24
5000	29	6.03	50.9	49.1	.98	-.02
5500	37	7.69	58.6	41.4	1.09	.18
6000	29	6.03	64.7	35.3	1.19	.40
6500	31	6.44	71.1	28.9	1.28	.61
7000	24	4.99	76.1	23.9	1.38	.82
7500	18	3.74	79.8	20.2	1.48	1.04
8000	17	3.53	83.4	16.6	1.58	1.25
8500	33	6.86	90.2	9.8	1.68	1.47
9000	29	6.03	96.3	3.7	1.78	1.68
9500	13	2.70	99.0	1.0	1.88	1.89
10000	4	.83	99.8	.2	1.98	2.11
10500	1	.20	100.0	.0	2.07	2.32

Figure 10.—*Simulation output: productivity tables (III).*

Table 6.—*Sensitivity of the simulation*

Change in run parameters	Productivity Tons/hr.	Productivity Effect
Standard run	16.66	
Decrease shearing time by 10 percent	17.48	Increase 5 percent
Decrease swing & drop time by 10 percent	16.84	([1])
Increase travel speed by 10 percent	16.70	([1])
Increase average number of trees in accumulator head load from 2.5 to 3.5	17.82	Increase 7 percent
Increase average number of trees within reach from 14 to 16	16.72	([1])
Increase average d.b.h. by 1 inch	23.94	Increase 43 percent
Increase frequency of mechanical delay from 1 percent to 2 percent of the cycles	14.64	Decrease 12 percent

[1]No major change in productivity observed for this level of change in parameter.

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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
- Segement 2—**feller/buncher**
  - Transactions—feller/buncher
  - Parameters
    - P1—not currently used.
    - P2—clock time marking start of cycle.
    - P3—next location of feller/buncher (distance in feet from the beginning of this strip or row).
    - P4—current location of feller bunches (distance down strip in feet).
    - P5—tree number being cut.
    - P6—limit for trees in accumulator head (number of trees).
    - P7—maximum size of skidder bunch attempted (sum of diameters).
    - P8—diameter of current tree.
    - P9—distance feller/buncher must travel to next set of trees.
    - P10—number of trees currently within reach of boom.
    - P11—actual sum of diameter of accumulator load.
    - P12—total volume in accumulator head.
    - P13—number of trees in load.

Functions

ACCLM	Distribution of the number of trees in accumulator loads.
DBH	Distribution of diameters in the stand.
FBDRP	Distribution of drop times.
FBMOV	Distribution of the distances feller must move to reach more trees.
FBSHR	Distribution of shear times.
MCDLY	Distribution of mechanical delay times in each cycle (including cycles with zero delay).
NMDLY	Distribution of nonmechanical delay times in each cycle (including cycles with zero delay).
REACH	Distribution of trees within reach from a random spot.
SNORM	Distribution used to obtain a normal distribution for sampling with a mean = 0, variance = 1. Lower end truncated.

Savevalues

ACLM1	Mean accumulator head limit (number of trees).
AVDBH	Mean stand diameter (inches × 100).
AVHGT	Mean stand height (feet).
AVVOL	Mean vol./acre (cu.ft. × 100).
BNCOM	Number of skidder bunches complete and ready for skidding.
BNDIA	Sum of diameters of trees in the bunch (inches).
BNDIF	Distance between bunches (feet).
BNLM1	Limit for skid bunch size— maximum sum of diameters.
BNLOC	Location of bunch (distance from end of strip).
BNTRE	Number of trees in a bunch.
BNVOL	Volume of bunch (cu.ft. × 100).
BRKTM	Total time spent on breaks (centi-minutes).
DAYS	Number of days worked.
DBH	Diameter breast high (d.b.h.) of current tree (inches).
DELNM	Total time lost to nonmechanical delays (centi-minutes).
DELYM	Total time lost to mechanical delays (centi-minutes).
FBACC	Total number of feller/buncher accumulator loads.
FBDIS	Total distance feller/buncher has traveled (feet).
FBGPH	Feller/buncher fuel usage (gal./hr.).
FBHR	Total time feller has worked (hours × 100).
FBOUT	Distance feller travels to get to the woods (feet).

FBTIM	Total time feller has been on job (minutes × 100).
FBTRE	Total trees cut.
FBTYP	Feller/buncher type; tracked = 0, rubber-tired = 1.
FBVOL	Total volume cut (cu.ft. × 100).
FTRV1	Mean travel speed (ft./min.).
FTRV2	Standard deviation of travel speed.
LASTB	Location of last bunch.
LBCFT	Density of plot species (lb./cu. ft.).
MVSTP	Distance feller/buncher travels between strips.
NUMFB	Number of feller/bunchers on the job.
STPLN	Length of strip or row (feet).
STRIP	Number of strips harvested.
TRPAC	Mean stand density (trees/acre).
WKDAY	Length of work shift (hours).

Switches

COFFE	Set by timer to indicate coffee break.
DAY	Set by timer to indicate beginning of work day.
FBMOV	Set by feller when he must move (no more trees in reach).
LUNCH	Set by timer to indicate lunch break.
STRIP	Set by feller/buncher when he has cut the last tree of current strip.

Tables

ACCTR	Trees per accumulator load.
ACCVL	Volume per accumulator load (cu.ft. × 100).
BDIA	Sum of diameter of trees in a skid bunch (inches).
BDIF	Distance between bunches (feet).
BLOC	Bunch location— distance down strip (feet).
BTREE	Number of trees in 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.
DROP	Swing and drop time.
FBSHR	Position and shear time.
FBTRV	All travel time.
MCDLY	Mechanical delays.
NMDLY	Nonmechanical delays.

Variables

ACCLM	Accumulator head size limit (number of trees).
BNDIF	Calculate distance between bunches (feet).
BREAK	Time between breaks (centi-minutes).
BRKTM	Time spent on breaks (centi-minutes).
BUNLM	Skidder bunch limit (sum of diameter).
DELNM	Nonmechanical delay time (centi-minutes).
DELYM	Mechanical delay time (centi-minutes).
FBDRP	Swing and drop time (centi-minutes).
FBHR	Total hours worked.
FBMOV	Distance feller/buncher must move to put more trees in reach (feet).
FBSHR	Shear time (centi-minutes).
FBTRV	Travel time (centi-minutes).
MCDLY	Length of mechanical delay (centi-minutes).
NEXTY	Next harvesting location down strip = current position + 95 percent distance traveled (allows for travel not in a straight line).
NIGHT	Remainder of 24 hours after work shift (centi-minutes).
NMDLY	Nonmechanical delay time (centi-minutes).
REACH	Number of trees within reach of boom at current feller/buncher position.
SPEED	Travel speed (ft./min.).
STEND	Distance to the end of strip (feet).
STPLN	Length of strip or plot (feet).
TDIAM	Tree diameter (inches).
TVOL	Tree volume (0.01 cu. ft.).
WKDAY	Length of work shift (centi-minutes).

APPENDIX B

PROGRAM LISTING

```
     / * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     *
     *        FELLER BUNCHER SIMULATOR
     *            UPDATED  JULY 1979
     *
     *
     *      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,X$AVVOL,X$AVDBH,X$AVHGT,X$TRPAC
 18         HELP        SYSTM,X$NUMFB,X$ACLM1,X$FBTYP,X$BNLM1
     *                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,X$NUMFB,X$FBTYP,X$BRKTM,X$DELYM,X$DELNM
     *          NUM OF FELLER BUNCHERS, FB TYPE,BREAKTIME,DELAY TIME
     *
 20         HELP        FELBN,X$FBTRE,X$FBVOL,X$BNCOM,X$FBHR,X$FBDIS
     *          TOT TREES,TOT VOL,SKID BUNCHES COMPLETED,FB HOURS,TOT DIST TRAVELED
     *
 21         HELP        FELBN,X$FBACC,X$LBCFT,X$FBVOL,X$FBGPH
     *          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
*
* . . . . . . . . . . . . . . . . . . . . . . . . . . .
*
* * * *  FN$SNORM IS USED TO OBTAIN A SAMPLING OF AN APPROXIMATELY
*           NORMAL DISTRIBUTION OF MEAN 0 AND STANDARD DEV 1
*
*        NOTE: TO AVOID DATA LOSS FROM INTERGERAZATION,
*              FUNCTION VALUES HAVE BEEN
*              MULTIPLIED BY 10
*        *  *  USE     MEAN+(FN$SNORM * 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
*
* . . . . . . . . . . . . . . . . . . . . . . . . . . .
*
*      TRACKED TYPE FELLER BUNCHER
*
* . . . . . . . . . . . . . . . . . . . . . . . . . . .
*
*
*      THIS SEGMENT IS A FELLER BUNCHER WITH A BOOM MOUNTED SHEAR
*         IT CAN BE USED AS A SINGLE STEM OR ACCUMULATING HEAD FB
*
*      THE FELLER BUNCHER IS ASSUMED TO WORK IN A ZIG-ZAG PATTERN
*         - OUT ONE STRIP BACK THE NEXT.
*
*      THE FB COMBINES MULTIPLE ACCUMULATOR HEAD BUNCHES TO OBTAIN A
*         BUNCH BIG ENOUGH FOR THE SKIDDER.
*
*
* . . . . . . . . . . . . . . . . . . . . . . . . . . .
*
*
* . . . . . . . . . . . . . . . . . . . . . . . . . . .
*
*                FELLER BUNCHER PARAMATER ASSIGNMENTS
*
*          P1    NOT USED
*          P2    CLOCK TIME
*          P3    CURRENT LOCATION OF FB
*          P4    BUNCH TIME
*          P5    TREE NUMBER
*          P6    CURRENT ACCUMULATOR LIMIT
*          P7    CURRENT BUNCH SIZE LIMIT
*          P8    TREE DIA
*          P9    DIST FB WILL TRAVEL
*          P10   # TREES IN REACH
*          P11   SUM OF DIAMETER IN ACC. HEAD
*          P12   TOTAL VOLUME IN ACC. HEAD
*          P13   NUMBER OF TREES IN LOAD
*
*
* * * *  GENERATE FELLER BUNCHERS , INITILIZE ACC HEAD
*
* * * *  DEFINING VARIABLES FOR FELLER BUNCHER
*
*
 BNDIF FVARIABLE  P4-X$LASTB           DISTANCE BETWEEN BUNCHES
 NEXTY FVARIABLE  P9*957100+P3         ACTUAL DIST DOWN STRIP (FT)
 STEND FVARIABLE  P3-X$STPLN           DISTANCE TO END OF STRIP
*
 FBTIM TABLE      MP2,0,25,25          OUTPUT TABLES FOR FB
 ACCVL TABLE      P12,0,500,20           CYCLE DATA
 ACCTR TABLE      P13,0,1,12
*
 BDIA  TABLE      X$BNDIA,0,5,25       TABLES OF SKIDDER
 BTREE TABLE      X$BNTRE,0,1,25         BUNCHES CREATED
 BDIF  TABLE      X$BNDIF,0,5,15
 BLOC  TABLE      X$BNLOC,0,20,50
 BVOL  TABLE      X$BNVOL,0,500,40
```

```
         /
         *
         * * * *   GENERATE FELLER BUNCHERS,INITIALIZE FIRST DIST,ACCUMULATOR HEAD
         *
 24      ACCFB GENERATE    ,,,1,10,15
         *
 25            SAVEVALUE   STRIP,1                 INITIALIZE STRIP COUNT
 26      INIT  ASSIGN      11,0                    INITIALIZE ACCUMULATOR HEAD
 27            ASSIGN      12,0
 28            ASSIGN      13,0
 29            ASSIGN      6,V$ACCLM               ACC. LOAD LIMIT
 30            ASSIGN      7,V$BUNLM               BUNCH SIZE LIMIT
 31            ASSIGN      9,X$FBOUT               DIST FB TRAVELS TO START WORK
 32            MARK        2                       MARK START OF CYCLE
         *
         * * * * FB MOVES TO NEXT LOCATION,RESETS SWITCH FBMOV,RECORDS
         *         TRAVEL DISTANCE AND TIME AND DETERMINES # OF TREES
         *         WITHIN REACH AT THIS LOCATION.
         *
 33      FBMOV QUEUE       FBTRV
 34            ADVANCE     V$FBTRV                 FB MOVES TO NEW LOCATION
 35            DEPART      FBTRV                   RECORD TRAVEL TIME
 36            SAVEVALUE   FBDIS+,P9                     AND DISTANCE
         *
 37            ASSIGN      10,V$REACH              DETERMINE # OF TREES IN REACH
 38            ASSIGN      4,P3                    ACTUAL DISTANCE DOWN THE STRIP OF
         *                                            THE FELLER BUNCHER
 39            ASSIGN      9,V$FBMOV               DISTANCE FB WILL HAVE TO MOVE
         *                                            WHEN DONE HERE
 40            ASSIGN      3,V$NEXTY               NEXT LOCATION OF FB
 41            LOGIC R     FBMOV                   RESET TO INDICATE FB NOT
         *                                            READY TO MOVE
         *
         * * * * CHECK IF FB HAS CARRIED A TREE TO THIS LOCATION
         *         IF SO GO TO DROP
         *
 42            TEST E      P13,0,DROP              IF # OF TREES IN HEAD > 0 DROP
         *
         * * * * TREE-    FELLER BUNCHER DEFINES AND SHEARS TREES UNTIL ACCUMULATOR
         *                  HEAD IS FULL OR UNTIL HE RUNS OUT OF
         *                  TREES WITHIN REACH
         *
 43      TREE  ASSIGN      5+,1                    TREE NUMBER
 44            ASSIGN      8,V$TDIAM               DBH
         *
 45            QUEUE       FBSHR
 46            ADVANCE     V$FBSHR                 SHEAR TREE
 47            DEPART      FBSHR                   RECORD SHEAR TIME
         *
 48            ASSIGN      11+,P8                  TOTAL SUM OF DBH OF LOAD
 49            ASSIGN      13+,1                   # OF TREES IN ACC HEAD
 50            SAVEVALUE   DBH,P8
 51            ASSIGN      12+,V$TVOL              TOTAL VOL OF ACC. LOAD
 52            ASSIGN      10-,1                   ONE LESS TREE IN REACH
         *
 53            TEST G      P10,0,DONE              IF NO MORE TREES HERE GO TO DONE
 54            TEST GE     P13,P6,TREE             IF ACC NOT FULL & A TREE IN REACH
         *                                            GO TO TREE TO CUT IT
 55            TRANSFER    ,DROP                   ACC HEAD FULL GO TO DROP
         *
 56      DONE  LOGIC S     FBMOV                   SET SWITCH THAT THE FB MUST MOVE
 57            TEST L      P3,V$STPLN,STRIP        IF AT END OF STRIP GO TO STRIP
 58            TEST E      X$BNTRE,0,DROP          IF BUNCH IS ALREADY STARTED,DROP LOAD
         *                                            OTHERWISE,CARRY TREES IN ACC. HEAD
         *                                            ALONG WITH (FBMOV)
 59            TRANSFER    ,FBMOV
 60      STRIP LOGIC S     STRIP                   SET SWITCH INDICATING END OF STRIP
         *
```

```
      / * * * DROP-   SWING AND DROP THE FB LOAD, ACCUMULATE LOAD STATISTICS
      *                 SEE IF THE BUNCH IS LARGE ENOUGH FOR SKIDDERS
      *
 61    DROP   QUEUE        DROP
 62           ADVANCE      VSFBDRP                  SWING AND DROP BUNCH
 63           DEPART       DROP                     RECORD SWING & DROP TIME
      *
 64           SAVEVALUE    BNLOC,P4                 DISTANCE DOWN STRIP
 65           SAVEVALUE    BNVOL+,P12               TOTAL VOLUME
 66           SAVEVALUE    BNDIA+,P11               TOTAL DIA OF LOAD
 67           SAVEVALUE    BNTRE+,P13               TOTAL NO OF TREES
      *
      * * * * DELAY-   IF A DELAY IS DUE TO OCCUR, IT HAPPENS HERE
      *
 68           QUEUE        MCDLY
 69           ADVANCE      VSMCDLY                  MECHANICAL DELAY
 70           DEPART       MCDLY
 71           QUEUE        NMDLY
 72           ADVANCE      VSNMDLY                  NON-MECHANICAL DELAY
 73           DEPART       NMDLY
      *
 74           SAVEVALUE    FBACC+,1                 KEEP TRACK OF NUMBER OF ACC, LOADS
 75           SAVEVALUE    FBTRE+,P13               FB RECORDS PRODUCTION OF
 76           SAVEVALUE    FBVOL+,P12                 BOQUETS AND OF TIME
 77           SAVEVALUE    FBTIM+,MP2
 78           TABULATE     FBTIM
 79           TABULATE     ACCVL
 80           TABULATE     ACCTR
 81           MARK         2                        REINITIALIZE ACC HEAD
 82           ASSIGN       11,0
 83           ASSIGN       12,0
 84           ASSIGN       13,0
 85           ASSIGN       6,VSACCLM                NEW ACCUMULATOR LIMIT
 86           ASSIGN       7,VSBUNLM                NEW BUNCH LIMIT
      *
 87           TEST L       XSBNDIA,P7,BUNCH
      *                                                       TO BUNCH
 88           GATE LS      FBMOV,TREE                       IF MORE TREES IN REACH
      *                                                       GO TO TREE FOR
      *                                                       ANOTHER ACC, LOAD
      *
      * * * * BUNCH-   TABULATE BUNCH DATA TO USE FOR SKIDDERS,REINITIALIZE
      *                  PARBN MATRIX ,CHECK IF FB IS AT END OF STRIP
      *
      *
 89    BUNCH  TABULATE     BDIA                     RECORD BUNCH DATA FOR SKID SEG
 90           TABULATE     BTREE
 91           TABULATE     BVOL
 92           TABULATE     BLOC
      *
 93           SAVEVALUE    BNDIF,VSBNDIF            DISTANCE BETWEEN BUNCHES
 94           TABULATE     BDIF
 95           SAVEVALUE    LASTB,P4
 96           SAVEVALUE    BNVOL,0                  REINITIALIZE BUNCH DATA
 97           SAVEVALUE    BNDIA,0                    FOR NEXT BUNCH
 98           SAVEVALUE    BNTRE,0
 99           SAVEVALUE    BNCOM+,1                 IF TIME FOR COFFEE OR LUNCH,
      *                                               TAKE BREAK
100           QUEUE        BREAK                     CHECK IF BREAK
101           GATE LS      COFFE,NOBRK               15 MINUTE COFFEE BREAK
102           ADVANCE      1500
103           LOGIC R      COFFE
104    NOBRK  GATE LS      LUNCH,QUIT
105           ADVANCE      3000                      30 MINUTE LUNCH BREAK
106           LOGIC R      LUNCH
      *
      * * * * QUIT-    TABULATE TIME ON BREAKS AND CHECK IF
      *                  IT'S TIME TO QUIT FOR THE DAY
      *
107    QUIT   SAVEVALUE    FBTIM+,MP2                TABULATE TIME SPENT ON BREAK
108           DEPART       BREAK
109           GATE LS      DAY                      IF SHIFT IS OVER, STOP UNTIL TOMORROW
110           MARK         2                        MARK START OF CYCLE
111           GATE LS      FBMOV,TREE               MORE TREES IN REACH -GO TO TREE
112           GATE LS      STRIP,FBMOV              IF NOT END OF STRIP -GO TO FBMOVE
      *
113           ASSIGN       3,VSSTEND                STRIP DISTANCE
114           SAVEVALUE    LASTB,0
115           SAVEVALUE    STRIP+,1                 COUNT STRIPS
116           LOGIC R      STRIP
117           TRANSFER     ,FBMOV
```

```
/ * * * INPUT DATA
*
*
 FBTRV FVARIABLE  P9*100/VSSPEED         TRAVEL TIME (DIST/SPEED) IN CENTIMIN,
*                                                          P9 = DISTANCE
 SPEED FVARIABLE  XSFTRV1+XSFTRV2*FNSSNORM/10     FELLER BUNCHER TRAVEL
 FBSHR FVARIABLE  FNSFBSHR               POSITION & SHEAR TIME
 FBDRP FVARIABLE  FNSFBDRP               SWING AND DROP TIMES
*
 ACCLM FVARIABLE  FNSACCLM               ACCUMULATOR HEAD LIMIT
 BUNLM FVARIABLE  XSBNLMI                SKIDDER BUNCH SIZE LIMIT
*
*
 REACH FVARIABLE  FNSREACH               NUMBER OF TREES WITHIN REACH
 FBMOV FVARIABLE  FNSFBMOV               DIST FB MUST MOVE TO REACH MORE TREES
 TDIAM FVARIABLE  FNSDBH                 SUPPLIED FROM STAND DBH DATA
 MCDLY FVARIABLE  FNSMCDLY               MECHANICAL DELAY
 NMDLY FVARIABLE  FNSNMDLY               NON-MECHANICAL DELAY
 STPLN VARIABLE   XSSTPLN
 TVOL  FVARIABLE  (133*P8*P8-283)/10     TREE VOL IN TERMS OF DIA(P8)
*                                        100 TH'S OF CU FT.
*
*          DEFINING FUNCTIONS - MACHINE DATA
*
*     THIS INPUT DATA WAS OBTAINED FROM ACTUAL TIME STUDIES
*          CARRIED OUT IN 1978
 ACCLM FUNCTION    RN2,D5                # TREES IN ACC HEAD
.22,1/.45,2/.73,3/.9,4/1.,5
*       POSITION AND SHEAR - PER STEM  TIME IN CENTI-MIN
 FBSHR FUNCTION    RN2,C9
0,0/.29,10/.68,20/.89,30/.97,40/.98,50/.99,60/.995,70/1.0,90
*
*       SWING AND DROP   TIME IN CENTI-MIN
 FBDRP FUNCTION    RN2,C8
0,0/.13,10/.80,20/.95,30/.98,40/.99,50/.995,60/1.0,70
*
*          DEFINING FUNCTIONS - STAND DATA
*
 DBH   FUNCTION    RN4,D7                TREE DIAMETER  INCHES
.05,3/.28,4/.58,5/.82,6/.96,7/.99,8/1.0,9
*
 REACH FUNCTION    RN3,C12               TREES IN REACH AT A GIVEN SPOT
0,2/.03,4/.1,6/.2,8/.6,16/.68,18/.75,20/.81,22/.86,24/.9,26/.95,30/1,36
*
 FBMOV FUNCTION    RN3,C9                DISTANCE FELLER MUST MOVE
0,0/.1,5/.25,10/.55,25/.75,35/.85,50/.9,60/.95,90/1.,120
*
 MCDLY FUNCTION    RN6,D11               MECHANICAL DELAY
.99,0/.991,50/.992,100/.993,150/.994,200/.995,250/.996,500/.997,1000
.998,2000/.999,3000/1.0,4000
*
 NMDLY FUNCTION    RN6,D13               NON-MECHANICAL DELAY
.985,0/.987,15/.989,25/.991,35/.992,40/.993,50/.994,75/.995,80/.996,100
.997,200/.998,300/.999,400/1.0,500
*
* * * * INITIAL CONDITIONS FOR STAND
*
*                INITIAL DATA TAKEN FROM MPH TIME STUDY
        INITIAL     XSAVDBH,550              AVE. DBH  (IN)*100
        INITIAL     XSAVHGT,43               AVE TREE HGT, APPROX 42'
        INITIAL     XSAVVOL,345000           CU FT/ACRE*100
        INITIAL     XSTRPAC,884              TREES/ACRE
        INITIAL     XSSTPLN,725              AVE. STRIP LENGTH
        INITIAL     XSMVSTP,35               DISTANCE BETWEEN STRIPS
        INITIAL     XSLBCFT,55               LB PER CU FT - RED MAPLE
        INITIAL     XSWKDAY,8                HRS IN A WORK DAY
*
* * * * INITIAL CONDITIONS FOR EQUIPMENT -DATA TAKEN FROM USFS MPH TIME STUDY
*
        INITIAL     XSACLM1,4                MAX # TREES IN ACC LOAD
        INITIAL     XSBNLM1,120              MAX ATTEMPTED SKID BUNCH SIZE
        INITIAL     XSFTRV1,49               MEAN TRAVEL SPEED  FT/MIN
        INITIAL     XSFTRV2,19               STD. DEV. TRAVEL SPEED  FT/MIN
        INITIAL     XSFBGPH,55               FB  GAL/HR*10
        INITIAL     XSFBTYP,0                DROTT 0   RUBBER TIRED 1
        INITIAL     XSFBOUT,100              DIST FB TRAVELS TO WOODS
*
*
        RMULT       ,,37
        START       5,,5,1
        END
```

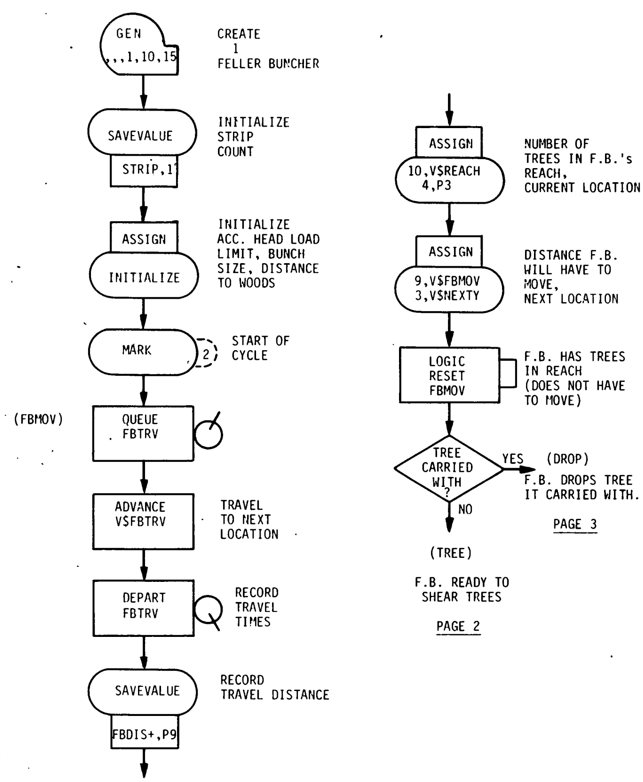
```
      SUBROUTINE SYSTM(IX)
      DIMENSION IX(5)
      DATA I/0/
C
    1 FORMAT(1H1,43X,'FULL  TREE  FIELD  CHIPPING  ',
     A 'SIMULATOR'/1H0,58X,'DEVELOPED  BY  THE'/1H ,46X,'NORTH CENTRAL '
     B,'FOREST  EXPERIMENT  STATION'/1H ,44X,'FOREST  SERVICE, U. S. DEP
     CT.  OF  AGRICULTURE'//1H0,29X, '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
      WRITE(6,7) BUNLM
      RETURN
C
      END
```

```
      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
```

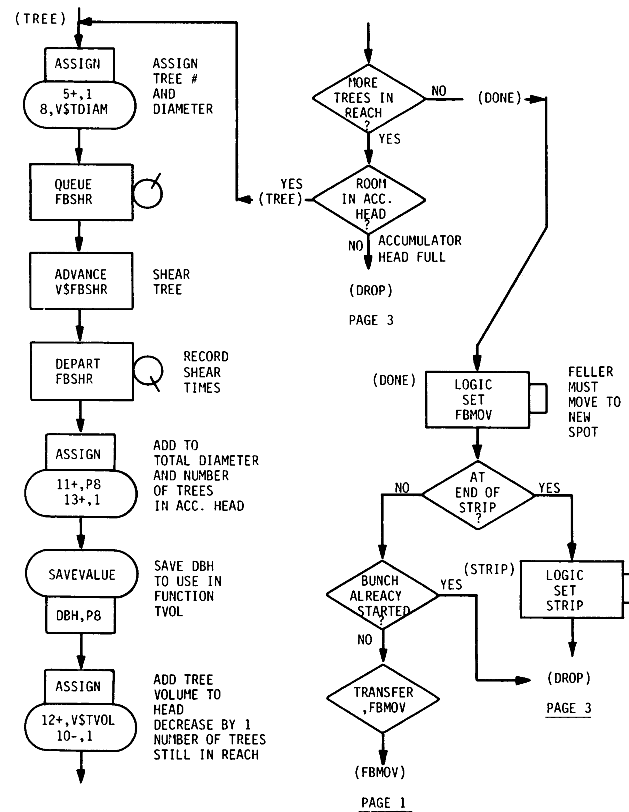
```
C  BREAK AND DELAY TIMES IN MINUTES
      BREAK=X3/100
      DELAY=X4/100
      DELNM=X5/100
      RETURN
   20 CONTINUE
      NTREE =  X1
      FBVOL = X2/100.
C FBVOL =   VOL. FELLED ALL MACHINES
      FBCNT = FBVOL/100.
C  FBCNT  FELLER-BUNCHER VOL. IN CUNITS.
      BNCOM = X3
C BNCOM =  BUNCHES 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

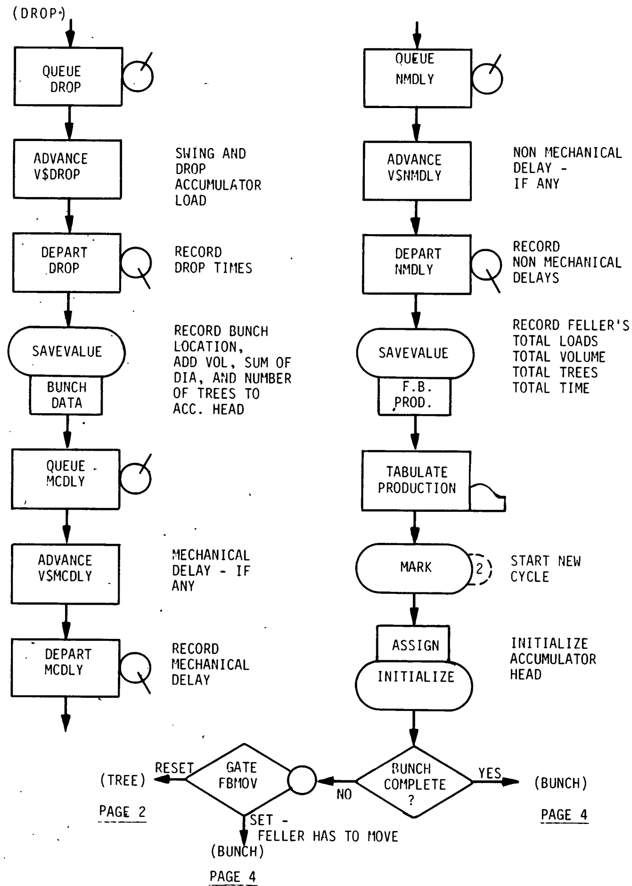
FELLER BUNCHER SEGMENT FLOW CHART
(Page 1 of 4)



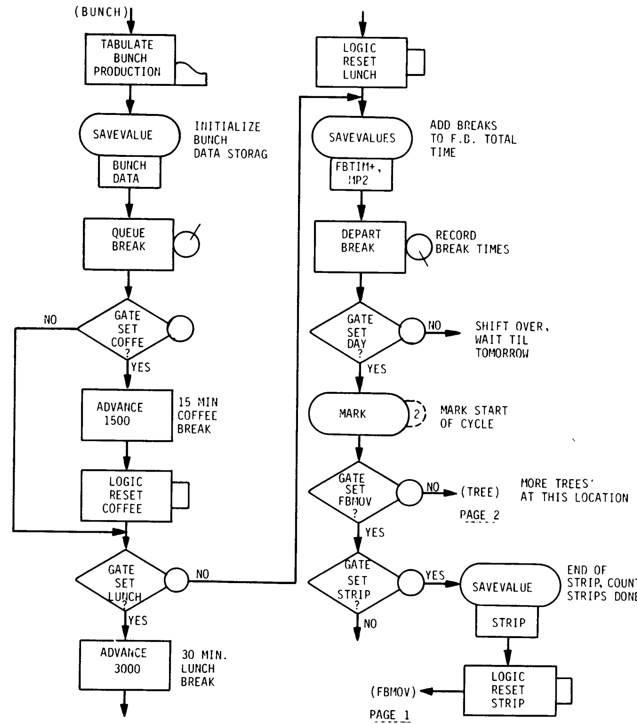
FELLER BUNCHER SEGMENT FLOW CHART
(Page 2 of 4)



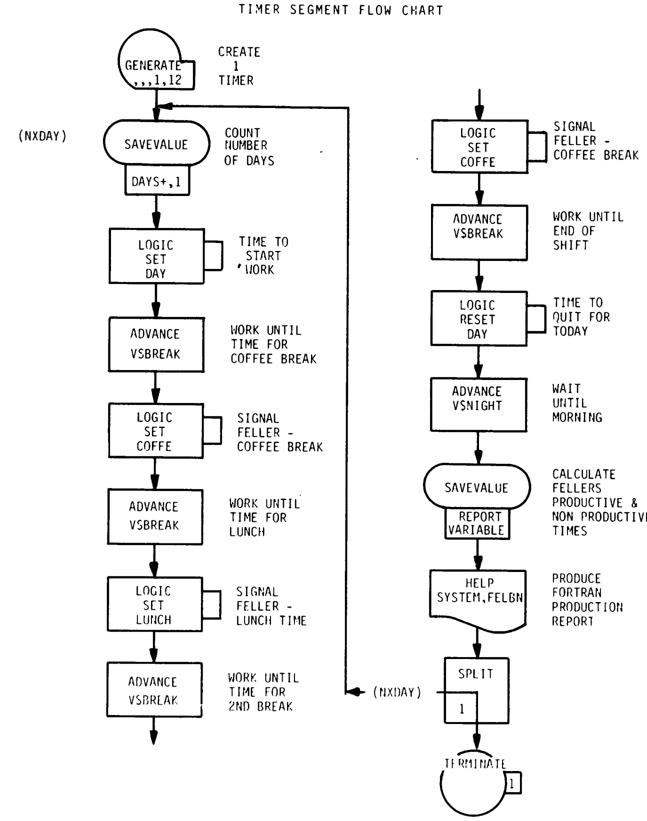
FELLER BUNCHER SEGMENT FLOW CHART
(Page 3 of 4)



FELLER BUNCHER SEGMENT FLOW CHART
(Page 4 of 4)



TIMER SEGMENT FLOW CHART



APPENDIX D

CARD FORMATS AND SOME GPSS INPUT TYPES

INPUT TYPES AND CARD FORMATS

For more detailed information see a GPSS manual.

1. SAVEVALUES

Savevalues are integers that can be accessed at any time during the run. In the program their form is X$NAME where NAME is the particular savevalue of interest.

Savevalues may be set to zero before the run begins, or may be given an initial value, X. This is done with an initial card of the format:

```
Col.  8          19

      INITIAL    X$NAME,X

      INITIAL    X$AVDBH,5
```

Sets the savevalue AVDBH to 5.

Note: These INITIAL cards must follow all other cards in the deck except the RMULT and START cards.

2. VARIABLES

Variables are used to calculate integers anytime they are called during the run; they can be defined as algebraic equations in terms of constants, savevalues, functions, or even other variables. They must be defined at the outset with the following card format:

```
Col.
2     8          19

NAME  FVARIABLE  Defining equation

TVOL  FVARIABLE  133*X$DBH*X$DBH/10
```

This defines that tree volume will be calculated by TVOL = 13.3 $(DBH)^2$.

During the simulation run, variables are called and computed by using V$NAME; for example:

```
Col.  8          19

      TABULATE   V$TVOL.
```

3. FUNCTIONS

Functions supply distributions to the program. They are called in the program by FN$NAME where NAME is the particular function of interest. There are several types of functions available; only one sample, a discrete function, will be given here.

Functions consist of two or more cards:

```
Col.
2     8          19

NAME  FUNCTION   RNI,DN
.X1,V1/.X2,V2/...
```

NAME is the function's name,

RNI = one of eight random number generators assigned to sample,

D = function type: discrete, continuous, list,

N = number of points in the function,

XI = percent of items in distribution at that value or less expressed as a decimal (cumulative), and

VI = value of the function.

For example, Data for function TDIA (FN$TDIA):

Tree diameter	Percent trees in size class	Cumulative percent
4	15	15
5	25	40
6	50	90
7	10	100

Card image forGPSS:

```
Col.
2     8          19
TDIA FUNCTION    RNI,D4
15,41/.4,5/.9,6/1.0,7.
```

4. RMULT and START

GPSS has eight random number generators available for use in the model. This allows use control over the sampling from distributions, making it possible to harvest the same stand repeatedly while isolating the effect of a change in one of the machine parameters, such as travel speed. The RMULT cards control the start of the sequence for each random-number generator.

The START card controls the number of days the simulation will run and the standard GPSS output.

The card formats are as follows:

```
Col.  8          19
      RMULT      A,B,C,D,E
      START      N,,S,1
```

A,B,C, etc., controls the sequence for random number generator, 1, 2, 3, etc., respectively.

N = number of days the simulation is to run, and

S = number of days between standard outputs.

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Winsauer, Sharon A.

1980. A program and documentation for simulation of a tracked feller/buncher. U.S. Department of Agriculture Forest Service, Research Paper NC-192, 26 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

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

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