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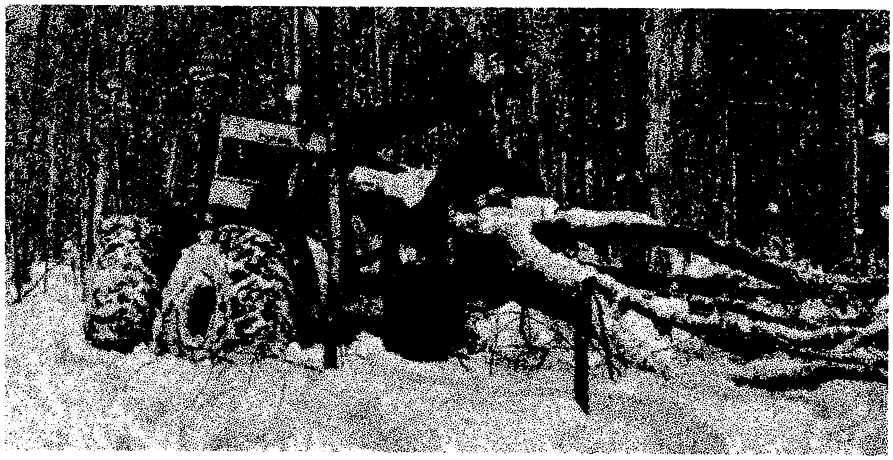
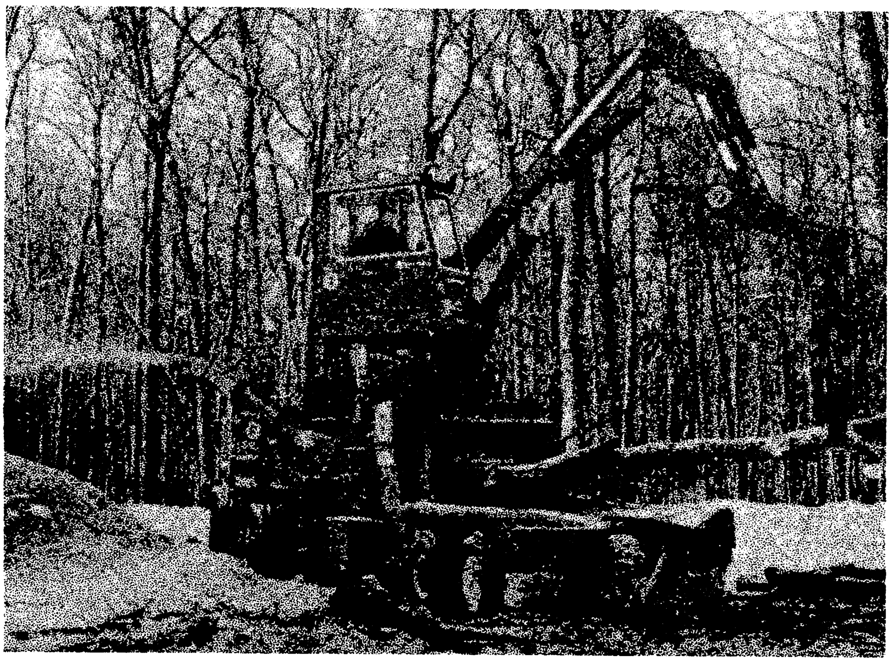
# A Program and Documentation for **Simulation of Grapple Skidders and a Whole-Tree Chipper**

Sharon A. Winsauer





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# A PROGRAM AND DOCUMENTATION FOR SIMULATION OF GRAPPLE SKIDDERS AND A WHOLE-TREE CHIPPER

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Computer simulation of forest harvesting systems is an efficient tool for resource management. The purpose of this paper is to document a computer model of a skidder-chipper system. The model was developed to provide a detailed study of the interaction between the skidders and the chipper. It allows the user to determine cost and productivity, machine efficiency, and causes of delays for various system configurations. Complete variable lists, program listings, and flow charts are included in Appendices A, B, and C.

## THE EQUIPMENT STUDIED

The equipment modeled are grapple-type skidders and a whole-tree chipper with a self-loading grapple (figs. 1 and 2). The simulation assumes that the felling was done far enough in advance of the skidders so there is no conflict between fellers and the skidders and that wood to be skidded is always available.

## MODEL OBJECTIVES

The primary objective of this model is a detailed look at productivity and efficiency of a given skidder-chipper combination (size of chipper, number and size of skidders). The trees to be skidded are assumed to be bunches left by earlier felling. The number of trees in each bunch can be obtained from the output of a feller/buncher simulation (Winsauer 1980, Winsauer and Bradley [In prep.]).

For input, the model requires data on the operating characteristics of the skidders and the chipper, the number of trees in each bunch, and stand conditions such as diameters of trees cut and skid distances.

After simulating the harvest of a stand, the model reports productivity figures for both types of equipment such as bunches, trees and volume skidded, trees and volumes chipped, and number of vans filled. Additional output gives the productive and delay times and causes for each type of equipment, etc.

## SIMULATION LANGUAGE—GPSS

The simulation is written in General Purpose Simulation System (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.

Most versions of GPSS have a standard output format that contains all the 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 centi minute; i.e., 1/100 of a minute. The equipment works one shift a day for the number of days chosen by the user. All volume measures are in 1/100 cubic foot of solid wood.

It is assumed that the trees in the plot have already been felled and to some degree bunched by

Figure 1.—*Grapple type skidder.*


Figure 2.—*Whole-tree chipper.*

either man or machine. To obtain simulation results involving the interaction of feller and skidders, it would be necessary to combine this model with a felling model.

The following assumptions are made about the system:

1. The equipment works one shift a day, then is turned off for the remainder of 24 hours.
2. Production reports and statistics are produced at the end of each 24-hour day, so they include any overtime that may have been worked on a shift.
3. Two 15-minute coffee breaks and one 30-minute lunch break are scheduled each shift. The chipper can take a break only when the van is full. The skidders can break when they reach the landing if, and only if, the chipper is on break.
4. Each skidder travels from landing to the woods along a "skid road." It then travels through the woods to a bunch, grapples it, and hauls it to a collection point where it can drop trees and rebunch if desired. It also has the option of returning for a second bunch before hauling to the landing. The load is skidded back to the landing along the skid road.
5. There is limited space at the landing for wood, so the skidder may have to wait for room before dropping the load.
6. The skidders can quit for the day only if the chipper has quit. The skidder always drops the bunch before quitting.
7. There is room for one van at the chipper. When the van is full, the chipper must wait for it to be moved out and another van moved in.
8. A van is considered full when the volume in the van—after the last load added—is equal to or greater than the volume indicated in X$VANCY. Since the model uses hundredths of cubic feet, this value should also be in hundredths. The van capacity must also be measured in the same type of volume used in the models; i.e., solid wood.
9. The chipper can take a break or quit for the day only after it has finished filling a van.
10. One specific chipper delay has been incorporated into the model. For a certain percent of the chip loads, X$PDELY, the chipper is delayed while the log is bucked to fit into the chipper opening. By setting X$PDELY to zero, the user can eliminate this delay source.
11. To avoid carrying excessive data through the model, the skidders and chippers draw d.b.h. values for the trees from separate, but identical, distribution functions. In this way there is a 1 to 1 correspondence between trees skidded and trees chipped. This required function DBH and DIAM to be identical except for the random number generator; one uses RN4, the other, RN5. These random number generators must be given identical seed values.

# MODEL DESCRIPTION

The model consists of three GPSS segments:
1. TIMER SEGMENT
2. SKIDDER SEGMENT
3. CHIPPER SEGMENT
and three 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 1/2-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 to finish filling the last van 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 SKIDDER SEGMENT (fig. 4) models one or more identical grapple-type skidders. Each skidder retrieves bunches of previously felled trees and skids them to a landing to be chipped.

The CHIPPER SEGMENT (fig. 5) models a whole-tree chipper with self-loading grapple. The chipper landing is located in or near the woods so that chip vans can be brought to the chipper.

# DATA INPUT

GPSS accepts input 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 VARIABLES. VARIABLES can be defined in terms of the input data available at the end of the deck allowing the user flexibility in data form while avoiding card shuffling in the main program. For example, a skidding time

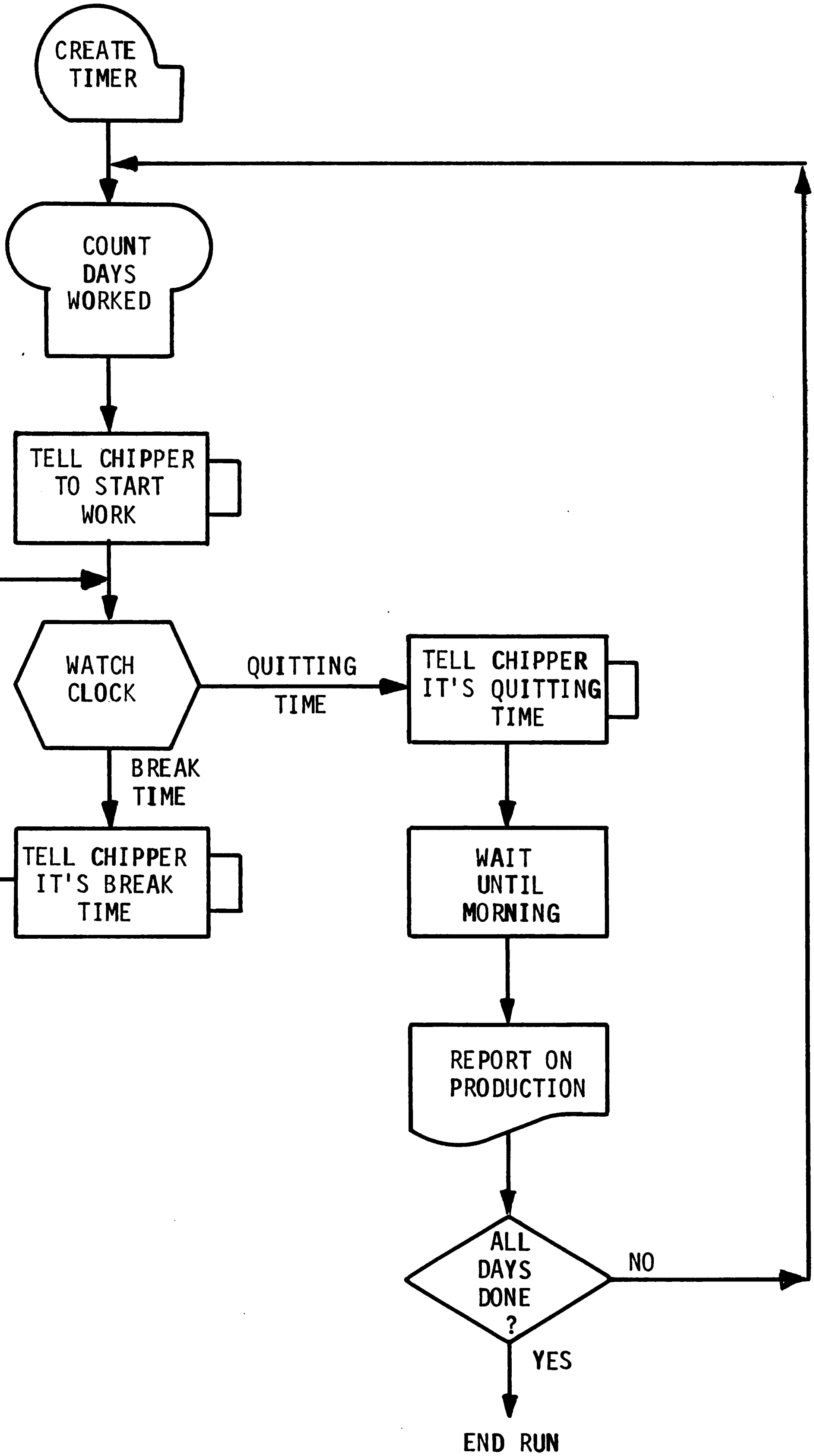


Figure 3.—*Timer segment--overview.*

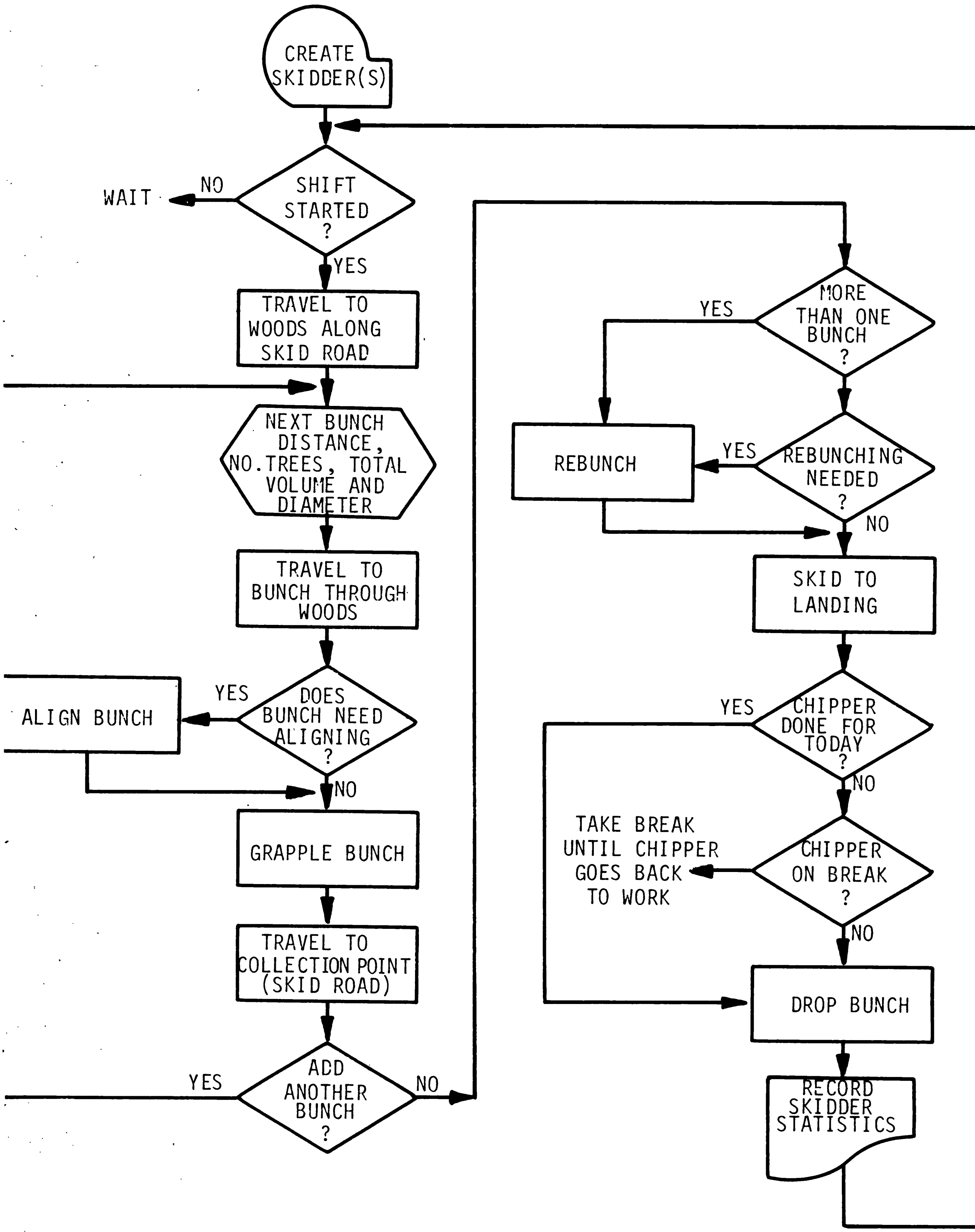


Figure 4.—*Skidder segment--overview.*

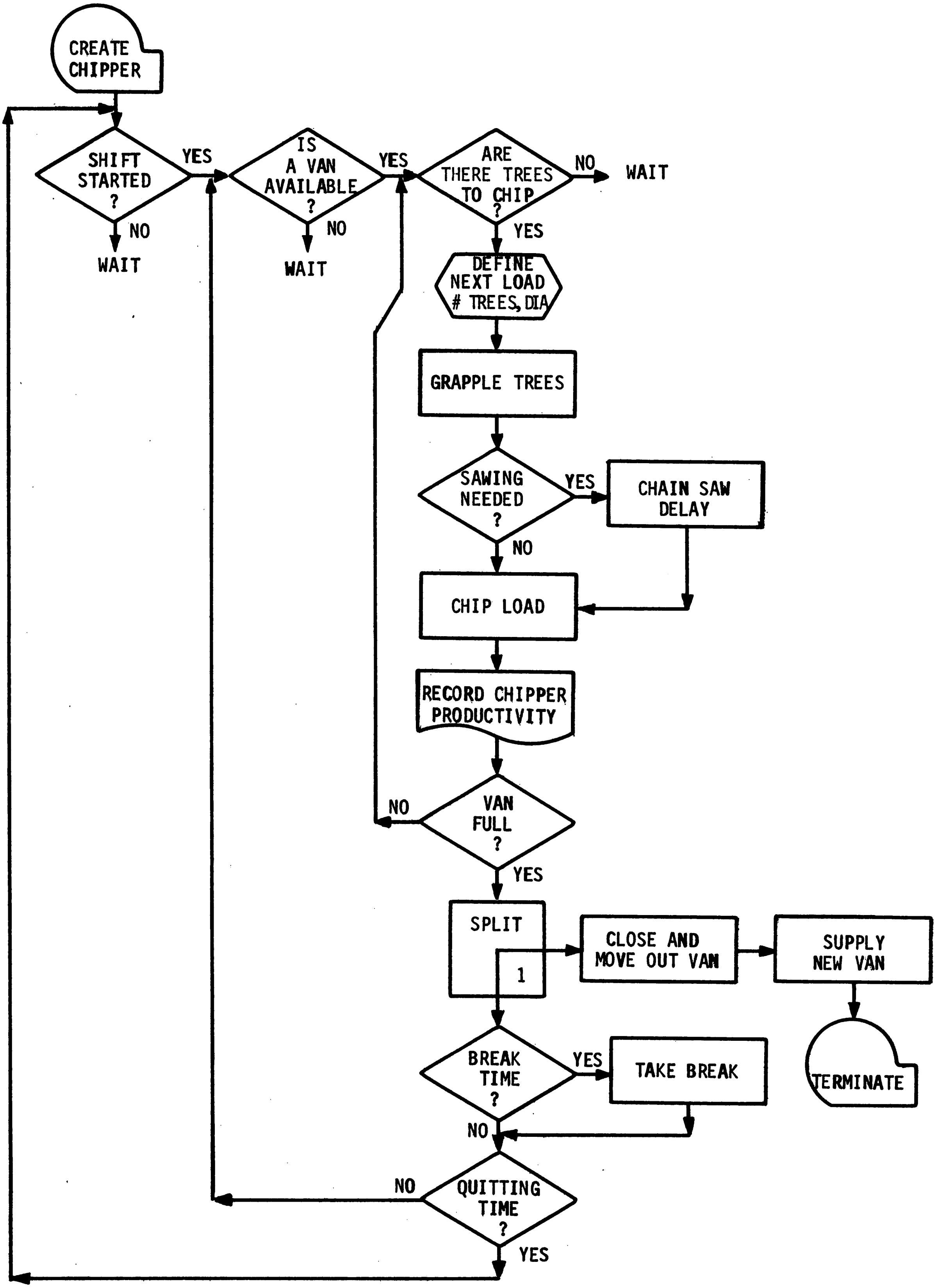


Figure 5.—*Chipper segment--overview.*

Table 1.—*GPSS data input forms*

| Input data type | Input form in GPSS | Example |
|---|---|---|
| Simple averages or constants | Initialized SAVEVALUES | Average d.b.h. = 6 inches |
| Range of values | Initialized SAVEVALUES for mean and one-half width of interval | Shear time = 0.10 to 0.14 minutes<br>= 0.12 ± 0.02 minutes |
| Equations | VARIABLES | Volume = 0.13 d.b.h.$^2$–0.28 |
| Frequency distributions | FUNCTIONS | D.b.h. (inches) 4 \| 5 \| 6 \| 7 \| 8<br>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<br>Mean = 10<br>Variance = 9 |

change from a constant (SAVEVALUE) to the product of rate times distance is accomplished by simply redefining the skid time variable and supplying the appropriate input cards.

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 entered simply for use in output tables. The actual input data cards follow the variable definitions and are supplied as FUNCTIONS or SAVEVALUES depending upon the VARIABLE definition.

# DATA REQUIRED BY MODEL

Input data describing the equipment and harvesting operation must be supplied to run the simulation.

There are four types of data to be supplied:

1. Stand data (table 2)
2. Machine data for skidders (table 3)
3. Machine data for chipper (table 4)
4. Simulation run control (table 5).

The sample output presented in this paper results from a case study using the data in tables 2-5 as input. These data were gathered from time studies carried out during Forest Service projects and are used to illustrate the model and its use. Bunch size and location data were taken from a simulation run of a tracked type feller/buncher (Winsauer 1980).

The data in the tables are empirical, so they represent the operating characteristics of this machine under given stand conditions. Different harvest conditions will require new input data.

# SIMULATION OUTPUT

The simulation run produces three pages of formatted output for each day of the run (figs. 6, 7, and 8). These present a summary of the stand data and cumulative productivity reports. Additional output is produced at the end of the run by the GPSS processor. This output supplies complete run details.

The first page of standard output (fig. 9) presents a simulation "map" listing all the blocks in the model and the number of transactions that have moved through each block. This is primarily of value while debugging the model. The listing of the QUEUE statistics provides detailed information on how time is spent and delays for each type of equipment. The SAVEVALUE list contains all the totals necessary to calculate productivity if the FORTRAN subroutines cannot be used.

Example:
CPHR = 4,230 = chipper hours x 100
CPTRE = 14,218 = trees chipped
CPVNS = 52 = vans filled
52/42.30 = 1.23 vans/hour
14,218/42.30 = 336 trees/hour
14,218/52 = 273.4 trees/van

The tables (figs. 10-11) provide additional details of the machine performance.

Table 2.—*Stand data*

| Data required | Case study | Form required by program | Name |
|---|---|---|---|
| Average stand diameter | 5.5 in d.b.h. | SAVEVALUE | X$AVDBH |
| Average stand volume | 3,450 cu ft/acre | SAVEVALUE | X$AVVOL |
| Average tree height | 43 ft | SAVEVALUE | X$AVHGT |
| Average trees/acre | 844 | SAVEVALUE | X$TRPAC |
| Density of wood | 55 lb/cu ft | SAVEVALUE | X$LBCFT |
| Energy equivalent-fuel | 150,000 BTU/gal | SAVEVALUE | X$FBTU |
| Energy equivalent-wood | 8,000,000 BTU/ton | SAVEVALUE | X$WBTU |
| Skid distance-road/track | 300 ft | VARIABLE | V$RDIST |
| Skid distance-woods | Distribution[1] | VARIABLE | V$WDIST |

| Distance (ft) | 0-5 | 5-10 | 10-15 | 15-20 | 20-25 | 25-30 | 30-35 |
|---|---|---|---|---|---|---|---|
| Percent time | 23 | 12 | 7 | 11 | 10 | 9 | 5 |

| Distance (ft) | 35-40 | 40-45 | 45-50 | 50-55 | 55-60 | 60-100 |
|---|---|---|---|---|---|---|
| Percent time | 2 | 3 | 4 | 2 | 2 | 10 |

| Data required | Case study | Form required by program | Name |
|---|---|---|---|
| Actual tree diameter | Diameter distribution: | FUNCTION | FN$DBH<br>FN$DIAM[2] |

| D.b.h (in.) | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|
| Percent trees | 5 | 23 | 30 | 24 | 14 | 3 |

| Data required | Case study | Form required by program | Name |
|---|---|---|---|
| Tree volume | Volume (cu ft)<br>= − 0.283 + 0.0031 (d.b.h.$^2$) tree height<br>= 0.283 + 0.133 (d.b.h.$^2$)<br>assuming tree height = 43 ft | VARIABLE | V$TVOL |
| Type of feller/buncher | Tracked | SAVEVALUE | X$FBTYP |
| Number of feller/bunchers | 1 | SAVEVALUE | X$NUMFB |
| Feller/buncher fuel consumption | 3.3 gal/ton | SAVEVALUE | X$FBGPT |
| Number of trees per bunch left by feller/buncher | Distribution-trees per bunch[1] | VARIABLE | V$NTBUN |

| Trees/bunch | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| Percent bunches | 0.4 | 2.1 | 3.5 | 3 | 6 | 5 | 4 | 6 |

| Trees/bunch | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|
| Percent bunches | 4 | 6 | 7 | 6 | 3 | 5 | 4 | 3 |

| Trees/bunch | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|
| Percent bunches | 4 | 4 | 3 | 4 | 4 | 6 |

[1]Distributions taken from simulation run of tracked feller/buncher (Winsauer 1980)

[2]FN$DBH and FN$DIAM are identical distribution functions used by skidders and chipper, respectively.

Table 3.—*Skidder data*

| Data required | Case study | Form required by program | Name |
|---|---|---|---|
| Number of skidders | 1 | SAVEVALUE | X$NUMSK |
| Maximum gapple load (total sum of diameters) | 150 inches | SAVEVALUE | X$MXSKD |
| Fuel consumption | 4 gal/hr | SAVEVALUE | X$SKGPH |
| Travel time along skid road/track-based on distance | Distance/speed<br>Road speed = 352 ft/min<br>= 4 mph | VARIABLE | V$RTRAV |
| Travel time in woods-based on distance | Distance/woods speed<br>Woods speed = ⅔ road speed | VARIABLE | V$WTRAV |
| Grapple time/bunch | Mean = 0.65 min<br>Std. dev. = .20 min | VARIABLE | V$GRAPL |
| Time to align bunch, if needed | Mean = .50 min<br>Std. dev. = .30 min | VARIABLE | V$ALIGN |
| Percent of bunches needing alignment before grappling | 1 percent | SAVEVALUE | X$ALIGN |
| Drop time per load | Mean = .30 min<br>Std. dev. = .15 min | VARIABLE | V$DROP |
| Rebunch time/load | Mean = .50 min<br>Std. dev. = .25 min | VARIABLE | V$REBUN |
| Percent of single bunches needing to be rebunched before hauling | 15 percent | SAVEVALUE | X$REBUN |
| Conditions under which the skidder will add another bunch before skidding to landing | Skid grapple load less than one/half its capacity | Boolean VARIABLE | BV$ADD |

Table 4.—*Chipper and van data*

| Data required | Case study | Form required by program | Name |
|---|---|---|---|
| Maximum chipper grapple load | 12 trees | SAVEVALUE | X$CMAX |
| Room at landing | 50 tree | SAVEVALUE | X$BUFLM |
| Chipper fuel consumption | 5.7 gal/hr | SAVEVALUE | X$CPGPH |
| Actual grapple load | Distribution: trees/ grapple load | VARIABLE | V$NGRAP |

| Number of trees | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| percent of grapple loads | 12 | 19 | 18 | 17 | 15 | 8 | 7 | 3 | 1 | 1 |

| Data required | Case study | Form required by program | Name |
|---|---|---|---|
| Grapple and chip time/load | 0.10 min per stem | VARIABLE | V$CHIP |
| Delay time for sawing | mean = 0.48 min<br>Std. dev. = .09 min | VARIABLE | V$CHSAW |
| Percent of chip loads needing sawing | 5 percent | SAVEVALUE | X$PDELY |
| Van capacity | 1,000 cu ft (solid wood) (approximately 30 tons) | SAVEVALUE | X$VANCY |
| Time to close van | 1 minute | VARIABLE | V$CLSVN |
| Time to change vans | 4 minutes | VARIABLE | V$VNWAT |

Table 5.—*Simulation run control*

| Data required | | Case study | Form required by program |
|---|---|---|---|
| Random number generators | Random number | Use | |
| | 1 | GPSS scheduler | RMULT CARD |
| | 2 | Generate normal random distributions | |
| | 3 | FUNCTIONS for wood distance, trees/bunch, chipper-grapple load | |
| | 4, 5 | Diameter distributions-these should have identical seed values and not be used for any other functions | |
| Number of days to simulate | 5 | | START CARD |
| Standard output | Every fifth day | | START CARD |

It should be noted that all of the output was obtained by random processes in the model. Therefore, the output data are themselves random numbers, 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.

# KNOWN DIFFERENCES BETWEEN SYSTEMS

The program listed in the Appendix is operational on a UNIVAC 1110 under an implementation 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 (lines 105-152 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 105 to 152 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

The simulation model provides an in-depth look at the operation of the system. This makes it possible to determine the effect on productivity and type of delays caused by changes in the system (table 6) or the stand. It can also be used in conjunction with other models to determine the cost and feasibility of a complete harvesting operation.

Some knowledge of GPSS allows the user to modify the model to meet his exact needs, making it even more useful and realistic.

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                              SAWLOG   SORTING   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 CUFT., AVERAGE VOLUME PER ACRE.
       5.50 INCHES, AVERAGE DBH.
      43.00 FEET, AVERAGE TREE HEIGHT.
     844.00 AVERAGE NUMBER OF TREES PER ACRE.
       7.18 FEET, AVERAGE TREE SPACING.

II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ANALYST.
  A.  FELLER-BUNCHERS.                      1  MACHINE(S)     TRACKED TYPE

  B.  SKIDDERS.                      1  MACHINE(S)     RUBBER-TIRED GRAPPLE SKIDDER(S).

       MAXIMUM SKID BUNCH HAS TOTAL SUM OF DIAMETER  150.00 INCHES


  C.  CHIPPER-LOADER.
       THE LOADER CAN TAKE A LOAD OF    12.TREES
      ENERGY BALANCE
             .33 GAL/TON - FELLER BUNCHER
             .10 GAL/TON - SKIDDER
             .14 GAL/TON - CHIPPER
             .57 TOTAL GAL/TON @
        85719.38 BTU/TON USED AS FUEL
      8000000.00 BTU/TON HARVESTED FROM WOOD

           93.33     ENERGY BENEFIT RATIO.
```

Figure 6.—*Simulation output--system and stand characteristics.*

```
S K I D D I N G   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.   42.48      HOURS WORKED BY SKIDDER(S).
       B.    1         NUMBER OF SKIDDER(S).
II.    A.  589         BUNCHES SKIDDED - ALL MACHINES.
                   1.76     AVERAGE NUMBER OF FELLER-BUNCHER BUNCHES COLLECTED.
                  24.20     AVERAGE NUMBER OF TREES PER SKIDDER BUNCH.
       B.14256         TREES SKIDDED - ALL MACHINES.
       C.52449.29      VOLUME SKIDDED - CU.FT. - ALL MACHINES.
       D.  405248      TOTAL DISTANCE SKIDDED.
       E. 1704.60      TOTAL TONS SKIDDED - ALL MACHINES.

III.   A.   13.87      BUNCHES SKIDDED PER MACHINE HOUR.
       B.  335.59      TREES SKIDDED PER MACHINE HOUR.
       C. 1234.68      VOL. SKIDDED PER MACHINE HOUR. - CU.FT.
       D.   40.13      TONS SKIDDED PER MACHINE HOUR.
IV.    A.  344.01      AVERAGE ONE-WAY SKID DISTANCE PER TRIP - FEET.
       B.    4.33      AVERAGE ROUND TRIP TIME IN MINUTES - ALL ACTIVITIES.
                   3.58     TIME - LANDING TO WOODS AND RETURN.
                    .30     PRODUCTIVE TIME - LANDING ACTIVITY.
                    .00     NON-PRODUCTIVE TIME-WAITING TO DROP AT CHIPPER.
                    .45     TIME ON BREAKS
V.     A.  169.92      TOTAL GALLONS USED.
                   4.00     GALLONS PER HOUR.
                    .10     GALLONS PER TON.
```

Figure 7.—*Simulation output--skidder productivity.*

```
        C H I P P E R - L O A D 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.   42.30     HOURS WORKED BY CHIPPER-LOADER.

II.   A. 3928        LOADS CHIPPED.
                    3.62     AVERAGE NUMBER OF STEMS PER LOAD.
                   13.32     AVERAGE VOLUME PER LOAD - CU.FT.
      B.   14218     TREES CHIPPED.
      C.52326.13     VOLUME CHIPPED - CU.FT.
      D. 1700.60     TONS CHIPPED.
      E.      52     VANS FILLED.
                   75.54     AVERAGE NUMBER OF LOADS PER VAN.
                 1006.27     AVERAGE VOLUME PER VAN - CU.FT.
                   32.70     AVERAGE TONS PER VAN.

III.  A.   92.86     LOADS CHIPPED PER MACHINE HOUR.
      B.  336.12     TREES CHIPPED PER MACHINE HOUR.
      C. 1237.02     VOLUME CHIPPED PER MACHINE HOUR - CU.FT.
      D.   40.20     TONS CHIPPED PER MACHINE HOUR.
      E.    1.23     VANS FILLED PER MACHINE HOUR.

IV.   A.   48.81     AVERAGE CHIPPING TIME PER VAN FILLED - ALL ACTIVITIES - MINUTES.
                   27.70     PRODUCTIVE TIME PER VAN - MINUTES.
                   21.11     NON-PRODUCTIVE TIME PER VAN - DUE TO EXTERNAL EVENTS - MINUTES.
                          10.58     LOADER WAITING FOR WOOD FROM SKIDDERS - MINUTES.
                           3.02     CHIPPER WAITING FOR VANS TO FILL - MINUTES.
                           1.75     BUCKING TIME
                           5.76     BREAK TIME

VI.   A.  241.11     TOTAL GALLONS OF FUEL USED.
                    5.70     GALLONS/HOUR.
                     .14     GALLONS/TON.
```

Figure 8.—*Simulation output--chipper productivity.*

*** 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 | 4 | 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 | 0, | 5 | 23 | 0, | 5 | 24 | 0, | 5 | 25 | 0, | 5 |
| 26 | 0, | 5 | 27 | 0, | 5 | 28 | 0, | 5 | 29 | 0, | 5 | 30 | 0, | 5 |
| 31 | 0, | 5 | 32 | 0, | 5 | 33 | 0, | 5 | 34 | 0, | 5 | 35 | 1, | 10 |
| OUTPT | 0, | 5 | SKDDR | 0, | 1 | START | 0, | 589 | 39 | 0, | 589 | 40 | 0, | 589 |
| 41 | 0, | 589 | 42 | 0, | 589 | 43 | 0, | 589 | 44 | 0, | 589 | 45 | 0, | 589 |
| WOODS | 0, | 1038 | 47 | 0, | 1038 | 48 | 0, | 1038 | NDBH | 0, | 14256 | 50 | 0, | 14256 |
| 51 | 0, | 14256 | 52 | 0, | 14256 | 53 | 0, | 1038 | 54 | 0, | 1038 | 55 | 0, | 1038 |
| 56 | 0, | 1038 | 57 | 0, | 1038 | 58 | 0, | 1038 | 59 | 0, | 1038 | 60 | 0, | 1038 |
| 61 | 0, | 1038 | 62 | 0, | 1038 | 63 | 0, | 1038 | 64 | 0, | 1038 | 65 | 0, | 1038 |
| ALIGN | 0, | 10 | 67 | 0, | 10 | 68 | 0, | 10 | GRAPL | 0, | 1038 | 70 | 0, | 1038 |
| 71 | 0, | 1038 | 72 | 0, | 1038 | 73 | 0, | 1038 | 74 | 0, | 1038 | 75 | 0, | 1038 |
| 76 | 0, | 1038 | 77 | 0, | 1038 | 78 | 0, | 589 | 79 | 0, | 200 | REBUN | 0, | 422 |
| 81 | 0, | 422 | 82 | 0, | 422 | SKLND | 0, | 589 | 84 | 0, | 589 | 85 | 0, | 589 |
| 86 | 0, | 589 | 87 | 0, | 589 | 88 | 0, | 589 | 89 | 0, | 589 | 90 | 0, | 589 |
| 91 | 0, | 589 | 92 | 0, | 589 | LAND | 0, | 589 | 94 | 0, | 589 | 95 | 0, | 15 |
| 96 | 0, | 15 | 97 | 0, | 15 | SWORK | 0, | 589 | 99 | 0, | 589 | 100 | 0, | 589 |
| 101 | 0, | 589 | 102 | 0, | 589 | 103 | 0, | 589 | 104 | 0, | 589 | 105 | 0, | 589 |
| 106 | 0, | 589 | 107 | 0, | 589 | 108 | 0, | 589 | 109 | 0, | 589 | 110 | 0, | 589 |
| 111 | 0, | 589 | 112 | 0, | 589 | 113 | 0, | 589 | 114 | 0, | 589 | 115 | 0, | 589 |
| 116 | 0, | 589 | WAIT | 1, | 589 | CHIPR | 0, | 1 | 119 | 0, | 1 | CSTRT | 0, | 5 |
| 121 | 0, | 5 | NEWLD | 0, | 3928 | 123 | 0, | 3928 | 124 | 0, | 3928 | 125 | 0, | 3928 |
| 126 | 0, | 3928 | 127 | 0, | 3928 | 128 | 0, | 3928 | 129 | 0, | 3928 | 130 | 0, | 3928 |
| 131 | 0, | 335 | GRAPE | 0, | 3928 | LOAD | 0, | 14218 | 134 | 0, | 14218 | 135 | 0, | 14218 |
| 136 | 0, | 14218 | 137 | 0, | 3928 | 138 | 0, | 3928 | 139 | 0, | 3928 | CHSAW | 0, | 194 |
| 141 | 0, | 194 | 142 | 0, | 194 | CHIP | 0, | 3928 | 144 | 0, | 3928 | 145 | 0, | 3928 |
| 146 | 0, | 3928 | 147 | 0, | 3928 | 148 | 0, | 3928 | 149 | 0, | 3928 | 150 | 0, | 3928 |
| 151 | 0, | 3928 | 152 | 0, | 3928 | 153 | 0, | 3928 | 154 | 0, | 3928 | 155 | 0, | 3928 |
| 156 | 0, | 3928 | 157 | 0, | 52 | FULVN | 0, | 104 | 159 | 0, | 52 | 160 | 0, | 52 |
| 161 | 0, | 52 | 162 | 0, | 10 | 163 | 0, | 10 | 164 | 0, | 10 | 165 | 0, | 10 |
| NOBRK | 0, | 52 | 167 | 0, | 5 | 168 | 0, | 5 | 169 | 0, | 5 | 170 | 0, | 5 |
| CDONE | 0, | 52 | 172 | 0, | 52 | 173 | 0, | 52 | 174 | 0, | 5 | 175 | 1, | 5 |
| LNKVN | 0, | 52 | 177 | 0, | 52 | 178 | 0, | 52 | 179 | 0, | 52 | 180 | 0, | 52 |
| 181 | 0, | 52 | | | | | | | | | | | | |

## QUEUE STATISTICS

| QUEUE NR | MAXIMUM CONTENTS | AVERAGE CONTENTS | TOTAL ENTRIES | ZERO ENTRIES | PERCENT ZEROS | AVERAGE TIME/TRANS | $ AVERAGE TIME/TRANS | TABLE NUMBER | CURRENT CONTENTS |
|---|---|---|---|---|---|---|---|---|---|
| SKBRK | 1 | .03 | 15 | 0 | 0.0 | 1777.67 | 1777.67 | 0 | 0 |
| CPBUF | 1 | .00 | 589 | 588 | 99.8 | .24 | 146.00 | 0 | 0 |
| CPBRK | 1 | .04 | 52 | 37 | 71.2 | 576.92 | 2000.00 | 0 | 0 |
| CHSAW | 1 | .01 | 194 | 0 | 0.0 | 47.11 | 47.11 | 0 | 0 |
| BFEMT | 1 | .07 | 3928 | 3530 | 89.9 | 14.39 | 142.04 | 0 | 0 |
| EVCPR | 1 | .02 | 3928 | 3896 | 99.2 | 4.07 | 500.00 | 0 | 0 |
| RDIST | 1 | .13 | 1178 | 0 | 0.0 | 85.00 | 85.00 | 0 | 0 |
| WTRAV | 1 | .02 | 2076 | 302 | 14.5 | 10.14 | 11.87 | 0 | 0 |
| ALIGN | 1 | .00 | 10 | 0 | 0.0 | 73.10 | 73.10 | 0 | 0 |
| GRAPL | 1 | .09 | 1038 | 0 | 0.0 | 64.99 | 64.99 | 0 | 0 |
| REBUN | 1 | .02 | 422 | 0 | 0.0 | 50.69 | 50.69 | 0 | 0 |
| CHIP | 1 | .19 | 3928 | 0 | 0.0 | 36.20 | 36.20 | 0 | 0 |

## SAVE VALUES

SAVEX

| NR | VALUE | NR | VALUE | NR | VALUE | NR | VALUE | NR | VALUE |
|---|---|---|---|---|---|---|---|---|---|
| WKDAY | 8 | DAYS | 5 | WDTIM | 210769 | SKLND | 44152 | SKTIM | 254921 |
| SKHR | 4248 | SKBRK | 26655 | SKNLN | 0 | CPTIM | 253850 | CPHR | 4250 |
| CPBRK | 29952 | BUCK | 9118 | CNPWD | 54992 | CNPVN | 15712 | AVVOL | 345000 |
| AVDBH | 550 | AVHGT | 43 | TRPAC | 844 | NUMFB | 1 | FBTYP | 0 |
| MXSKD | 150 | NUMSK | 1 | CMAX | 12 | WBTU | 8000000 | LBCFT | 65 |
| FBGPT | 33 | FBTU | 150000 | SKGPH | 400 | SKVOL | 5244929 | CPGPH | 570 |
| CPVOL | 5232613 | SKBUN | 589 | SKTRE | 14256 | SKADD | 1038 | SDIST | 405248 |
| CPTRE | 14218 | CPVNS | 52 | CPLOD | 3928 | NTBUF | 38 | BUFLM | 50 |
| RDIST | 353400 | DBH | 4 | WDIST | 51848 | ALIGN | 10 | REBUN | 150 |
| PDELY | 50 | VNCON | 0 | VANCY | 100000 | ROAD | 300 | HALF | 85 |
| SPEED | 352 | GRPL1 | 65 | GRPL2 | 20 | ALGN1 | 50 | ALGN2 | 30 |
| REBN1 | 50 | REBN2 | 25 | DROP1 | 30 | DROP2 | 15 | CHSW1 | 47 |
| CHSW2 | 9 | VNWT1 | 400 | VNWT2 | 0 | CLSV1 | 100 | CLSV2 | 0 |

## SKIDDER - TIME IN WOODS ( MIN. X 100 )

| TABLE | ENTRIES IN TABLE | MEAN ARGUMENT | STANDARD DEVIATION | SUM OF ARGUMENTS |
|---|---|---|---|---|
| WDTIM | 589 | 357.84 | 84.01 | 210769. |

| UPPER LIMIT | OBSERVED FREQUENCY | PERCENT OF TOTAL | CUMULATIVE PERCENTAGE | CUMULATIVE REMAINDER | MULTIPLE OF MEAN | DEVIATION FROM MEAN |
|---|---|---|---|---|---|---|
| 250 | 80 | 13.58 | 13.6 | 86.4 | .69 | -1.28 |
| 300 | 91 | 15.45 | 29.0 | 71.0 | .83 | -.68 |
| 350 | 86 | 14.60 | 43.6 | 56.4 | .97 | -.09 |
| 400 | 142 | 24.11 | 67.7 | 32.3 | 1.12 | .50 |
| 450 | 123 | 20.88 | 88.6 | 11.4 | 1.26 | 1.10 |
| 500 | 37 | 6.28 | 94.9 | 5.1 | 1.40 | 1.69 |
| 550 | 21 | 3.57 | 98.5 | 1.5 | 1.54 | 2.29 |
| 600 | 7 | 1.19 | 99.7 | .3 | 1.68 | 2.88 |
| 650 | 1 | .17 | 99.8 | .1 | 1.82 | 3.48 |
| 700 | 1 | .17 | 100.0 | .0 | 1.96 | 4.07 |

## NUMBER OF TREES PER SKIDDER BUNCH

| TABLE | ENTRIES IN TABLE | MEAN ARGUMENT | STANDARD DEVIATION | SUM OF ARGUMENTS |
|---|---|---|---|---|
| BNTRE | 589 | 24.20 | 6.03 | 14256. |

| UPPER LIMIT | OBSERVED FREQUENCY | PERCENT OF TOTAL | CUMULATIVE PERCENTAGE | CUMULATIVE REMAINDER | MULTIPLE OF MEAN | DEVIATION FROM MEAN |
|---|---|---|---|---|---|---|
| 16 | 37 | 6.28 | 6.3 | 93.7 | .66 | -1.36 |
| 18 | 75 | 12.73 | 19.0 | 81.0 | .74 | -1.03 |
| 20 | 84 | 14.26 | 33.3 | 66.7 | .82 | -.69 |
| 22 | 64 | 10.87 | 44.1 | 55.9 | .90 | -.36 |
| 24 | 91 | 15.45 | 59.6 | 40.4 | .99 | -.03 |
| 26 | 64 | 10.87 | 70.5 | 29.5 | 1.07 | .29 |
| 28 | 38 | 6.45 | 76.9 | 23.1 | 1.16 | .62 |
| 30 | 32 | 5.43 | 82.3 | 17.7 | 1.24 | .96 |
| 32 | 32 | 5.43 | 87.8 | 12.2 | 1.32 | 1.29 |
| 34 | 20 | 3.40 | 91.2 | 8.8 | 1.40 | 1.62 |
| 36 | 27 | 4.58 | 95.8 | 4.2 | 1.49 | 1.95 |
| 38 | 17 | 2.89 | 98.6 | 1.4 | 1.57 | 2.29 |
| OVERFLOW | 8 | 1.36 | 100.0 | .C | | |

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

| TABLE | ENTRIES IN TABLE | MEAN ARGUMENT | STANDARD DEVIATION | SUM OF ARGUMENTS |
|---|---|---|---|---|
| BNVOL | 589 | 8904.80 | 2246.71 | 5244929. |

| UPPER LIMIT | OBSERVED FREQUENCY | PERCENT OF TOTAL | CUMULATIVE PERCENTAGE | CUMULATIVE REMAINDER | MULTIPLE OF MEAN | DEVIATION FROM MEAN |
|---|---|---|---|---|---|---|
| 5000 | 1 | .17 | .1 | 99.8 | .56 | -1.74 |
| 5500 | 2 | .34 | .5 | 99.5 | .61 | -1.52 |
| 6000 | 20 | 3.40 | 3.9 | 96.1 | .67 | -1.29 |
| 6500 | 52 | 8.83 | 12.7 | 87.3 | .73 | -1.07 |
| 7000 | 59 | 10.02 | 22.8 | 77.2 | .78 | -.84 |
| 7500 | 60 | 10.19 | 32.9 | 67.1 | .84 | -.62 |
| 8000 | 51 | 8.66 | 41.6 | 58.4 | .89 | -.40 |
| 8500 | 51 | 8.66 | 50.3 | 49.7 | .95 | -.18 |
| 9000 | 48 | 8.15 | 58.4 | 41.6 | 1.01 | .04 |
| 9500 | 46 | 7.81 | 66.2 | 33.8 | 1.07 | .26 |
| 10000 | 39 | 6.62 | 72.8 | 27.2 | 1.12 | .48 |
| 10500 | 21 | 3.57 | 76.4 | 23.6 | 1.18 | .71 |
| 11000 | 29 | 4.92 | 81.3 | 18.7 | 1.24 | .93 |
| 11500 | 23 | 3.90 | 85.2 | 14.8 | 1.29 | 1.16 |
| 12000 | 20 | 3.40 | 88.6 | 11.4 | 1.35 | 1.38 |
| 12500 | 10 | 1.70 | 90.3 | 9.7 | 1.40 | 1.60 |
| 13000 | 15 | 2.55 | 92.9 | 7.1 | 1.46 | 1.82 |
| 13500 | 13 | 2.21 | 95.1 | 4.9 | 1.52 | 2.05 |
| 14000 | 15 | 2.55 | 97.6 | 2.4 | 1.57 | 2.27 |
| 14500 | 8 | 1.36 | 99.0 | 1.0 | 1.63 | 2.49 |
| 15000 | 4 | .67 | 99.7 | .3 | 1.68 | 2.71 |
| 15500 | 2 | .34 | 100.0 | .0 | 1.74 | 2.94 |

Figure 10.—*Simulation output--productivity tables I.*

## VOLUME PER CHIPPER LOAD (CU.FT. X 100)

| TABLE | ENTRIES IN TABLE | MEAN ARGUMENT | STANDARD DEVIATION | SUM OF ARGUMENTS |
|---|---|---|---|---|
| CPVOL | 3928 | 1332.13 | 815.81 | 5232613. |

| UPPER LIMIT | OBSERVED FREQUENCY | PERCENT OF TOTAL | CUMULATIVE PERCENTAGE | CUMULATIVE REMAINDER | MULTIPLE OF MEAN | DEVIATION FROM MEAN |
|---|---|---|---|---|---|---|
| 200 | 145 | 3.69 | 3.7 | 96.3 | .15 | -1.39 |
| 400 | 243 | 6.19 | 9.9 | 90.1 | .30 | -1.14 |
| 600 | 291 | 7.41 | 17.3 | 82.7 | .45 | -.89 |
| 800 | 502 | 12.78 | 30.1 | 69.9 | .60 | -.65 |
| 1000 | 404 | 10.29 | 40.4 | 59.6 | .75 | -.40 |
| 1200 | 327 | 8.32 | 48.7 | 51.3 | .90 | -.16 |
| 1400 | 439 | 11.18 | 59.9 | 40.1 | 1.05 | .08 |
| 1600 | 323 | 8.22 | 68.1 | 31.9 | 1.20 | .32 |
| 1800 | 247 | 6.29 | 74.4 | 25.6 | 1.35 | .57 |
| 2000 | 241 | 6.14 | 80.5 | 19.5 | 1.50 | .81 |
| 2200 | 225 | 5.73 | 86.2 | 13.8 | 1.65 | 1.06 |
| 2400 | 146 | 3.72 | 89.9 | 10.1 | 1.80 | 1.31 |
| 2600 | 101 | 2.57 | 92.5 | 7.5 | 1.95 | 1.55 |
| 2800 | 76 | 1.93 | 94.5 | 5.5 | 2.10 | 1.80 |
| 3000 | 66 | 1.68 | 96.1 | 3.9 | 2.25 | 2.04 |
| 3200 | 50 | 1.27 | 97.4 | 2.6 | 2.40 | 2.29 |
| 3400 | 32 | .81 | 98.2 | 1.8 | 2.55 | 2.53 |
| 3600 | 11 | .28 | 98.5 | 1.5 | 2.70 | 2.78 |
| 3800 | 18 | .45 | 99.0 | 1.0 | 2.85 | 3.03 |
| 4000 | 11 | .28 | 99.2 | .7 | 3.00 | 3.27 |
| 4200 | 8 | .20 | 99.4 | .5 | 3.15 | 3.52 |
| 4400 | 4 | .10 | 99.5 | .4 | 3.30 | 3.76 |
| 4600 | 8 | .20 | 99.7 | .2 | 3.45 | 4.01 |
| 4800 | 3 | .07 | 99.8 | .1 | 3.60 | 4.25 |
| 5000 | 4 | .10 | 99.9 | .0 | 3.75 | 4.50 |
| 5200 | 2 | .05 | 100.0 | .0 | 3.90 | 4.74 |
| 5400 | 1 | .02 | 100.0 | .0 | 4.05 | 4.99 |

## CHIP TIME PER LOAD (MIN. X 100)

| TABLE | ENTRIES IN TABLE | MEAN ARGUMENT | STANDARD DEVIATION | SUM OF ARGUMENTS |
|---|---|---|---|---|
| CPTIM | 3928 | 56.99 | 71.65 | 223850. |

| UPPER LIMIT | OBSERVED FREQUENCY | PERCENT OF TOTAL | CUMULATIVE PERCENTAGE | CUMULATIVE REMAINDER | MULTIPLE OF MEAN | DEVIATION FROM MEAN |
|---|---|---|---|---|---|---|
| 20 | 1160 | 29.53 | 29.5 | 70.5 | .35 | -.51 |
| 40 | 1189 | 30.27 | 59.8 | 40.2 | .70 | -.23 |
| 60 | 742 | 18.89 | 78.7 | 21.3 | 1.05 | .04 |
| 80 | 331 | 8.43 | 87.1 | 12.9 | 1.40 | .32 |
| 100 | 111 | 2.83 | 89.9 | 10.1 | 1.75 | .60 |
| 120 | 71 | 1.81 | 91.8 | 8.2 | 2.11 | .87 |
| 140 | 44 | 1.12 | 92.9 | 7.1 | 2.46 | 1.16 |
| 160 | 30 | .76 | 93.6 | 6.4 | 2.81 | 1.44 |
| 180 | 32 | .81 | 94.5 | 5.5 | 3.16 | 1.72 |
| 200 | 20 | .50 | 95.0 | 5.0 | 3.51 | 2.00 |
| 220 | 31 | .78 | 95.7 | 4.3 | 3.86 | 2.28 |
| 240 | 27 | .68 | 96.4 | 3.6 | 4.21 | 2.55 |
| 260 | 27 | .68 | 97.1 | 2.9 | 4.56 | 2.83 |
| 280 | 23 | .58 | 97.7 | 2.3 | 4.91 | 3.11 |
| 300 | 13 | .33 | 98.0 | 2.0 | 5.26 | 3.39 |
| 320 | 14 | .35 | 98.4 | 1.6 | 5.62 | 3.67 |
| 340 | 9 | .22 | 98.6 | 1.4 | 5.97 | 3.95 |
| 360 | 6 | .15 | 98.8 | 1.2 | 6.32 | 4.23 |
| 380 | 4 | .10 | 98.9 | 1.1 | 6.67 | 4.51 |
| 400 | 4 | .10 | 99.0 | 1.0 | 7.02 | 4.79 |
| 420 | 4 | .10 | 99.1 | .9 | 7.37 | 5.07 |
| 440 | 1 | .02 | 99.1 | .8 | 7.72 | 5.35 |
| 460 | 1 | .02 | 99.1 | .8 | 8.07 | 5.62 |
| 480 | 2 | .05 | 99.2 | .8 | 8.42 | 5.90 |
| 520 | 10 | .25 | 99.4 | .5 | 9.12 | 6.46 |
| 540 | 13 | .33 | 99.8 | .2 | 9.48 | 6.74 |
| 560 | 6 | .15 | 99.9 | .0 | 9.83 | 7.02 |
| 580 | 2 | .05 | 100.0 | .0 | 10.18 | 7.30 |
| OVERFLOW | 1 | .02 | 100.0 | .0 | | |

Figure 11.—*Simulation output--productivity tables II.*

Table 6.—*Productivity and delays of two system configurations*

| | System 1 | | System 2 | |
|---|---|---|---|---|
| | One skidder | One chipper | Two skidders | One chipper |
| Total machine hours worked | 42.39 | 42.21 | 81.06 | 40.42 |
| Percent productive time | 89.7 | 56.6 | 59.6 | 75.4 |
| Percent nonproductive time | | | | |
| Total delay | 10.3 | 43.3 | 40.4 | 24.6 |
| Breaks | 10.3 | 11.8 | 6.6 | 12.4 |
| Wait to drop wood | 0.0 | | 33.8 | |
| Wait for wood to chip | | 21.9 | | 0.0 |
| Wait for bucking | | 3.3 | | 4.6 |
| Wait for vans | | 6.3 | | 7.6 |
| Total trees | 14,268 | | 17,843 | |
| Total vans filled | 52 | | 65 | |
| Total tons processed | 1,706 | | 2,132 | |

# APPENDIX A
# VARIABLE LISTS AND DEFINITIONS

IMPLICIT TIME UNIT—centi-minute
MODEL SEGMENTS, TRANSACTIONS, AND PARAMETERS

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

Segment 2—SKIDDER(S)
- Transactions—One for each skidder.
- Parameters
  - P1—not used.
  - P2—clock time.
  - P3—total number of trees in skid load.
  - P4—total d.b.h. (inches) in skid load.
  - P5—total volume of skid load.
  - P6—number of feller/buncher bunches combined in this skid load.
  - P7—road distance.
  - P8—woods distance.
  - P9—number of trees in feller/buncher bunch.
  - P10—counter for d.b.h. loop.
  - P11—total sum of diameter in feller/buncher bunch.
  - P12—total volume of feller/buncher bunch.

Segment 3—CHIPPER
- Transactions—One chipper-loader. When it splits, parent transaction remains as chipper while offspring becomes full van.
- Parameters
  - P1—clock time.
  - P2—number of trees in chipper-grapple load.
  - P3—volume of load.
  - P4—sum of diameter of load (inches).
  - P5—loop counter.

## FACILITY

CPBUF Chipper buffer—area where skidders drop logs within reach of chipper.

## FUNCTIONS

DBH Distribution of diameters in the stand—used by skidder.

DIAM Identical diameter distribution—used by chipper.

NGRAP Distribution of the number of trees per chipper—grapple load.

NTBUN Distribution of number of trees in each bunch left by feller/buncher.
SNORM Used to obtain a normal distribution for sampling.
WDIST Distribution of bunches in the woods.

## QUEUES

ALIGN Time skidder spends aligning bunches.
BFEMT Time chipper waits for wood.
CHIP Chipping time.
CHSAW Time spent bucking logs.
CPBRK Time chipper spends on break.
CPBUF Skidder time waiting to drop load.
EVCPR Chipper time waiting for empty van.
GRAPL Skidder grapple time.
RDIST Skidder travel time on road.
REBUN Time spent rebunching a skid load.
SKBRK Time skidders spend on break.
WTRAV Skidder travel time in woods.

## SAVEVALUES

ALGN1 Time to align bunch—mean (centi-minutes).
ALGN2 Time to align bunch—standard deviation (centi-minutes).
ALIGN Percent of bunches needing alignment. NOTE: Must be three digits in terms of thousandths.
AVDBH Average stand diameter (inches x 10).
AVHGT Average tree height (feet).
AVVOL Average stand volume (cubic feet x 100).
BUCK Chipper delay time due to bucking (centi-minutes).
BUFLM Available room at chipper (number of logs).
CHSW1 Chain saw time to buck log—mean (centi-minutes).
CHSW2 Chain saw time—standard deviation (centi-minutes).
CLSV1 Time to close van—mean (centi-minutes).
CLSV2 Time to close van—standard deviation (centi-minutes).
CMAX Maximum chipper load (number of trees).
CNPVN Chipper nonproductive time waiting for vans (centi-minutes).
CNPWD Chipper nonproductive time waiting for wood to chip (centi-minutes).
CPBRK Chipper time spent on breaks (centi-minutes).
CPGPH Chipper fuel consumption (gallons/hour).
CPHR Total chipper time (hours x 100).
CPLOD Total number of chipper-grapple loads chipped.
CPTIM Total chipper time (centi-minutes).
CPTRE Total trees chipped.
CPVNS Total vans filled.
CPVOL Total volume chipped (cubic feet x 100).
DAYS Number of current day.
DBH Diameter of current tree (inches).
DROP1 Time needed for skidder to drop bunch—mean (centi-minutes).
DROP2 Time needed to drop bunch—standard deviation (centi-minutes).
FBGPT Feller/buncher fuel usage (gallons/ton).
FBTU Btu's in fuel per gallon.
FBTYP Feller/buncher type. 0 = tracked; 1 = rubber tired.
GRPL1 Skidder grapple time/bunch—mean (centi-minutes).
GRPL2 Grapple time/bunch—standard deviation (centi-minutes).
HALF Skid load limit to add more to the load (sum of diameters).
LBCFT Density of wood (pounds/cubic feet).
MXSKD Maximum skidder grapple load—total sum of diameter (inches).
NTBUF Current number of trees at the chipper.
NUMFB Number of feller/bunchers used to fell trees.
NUMSK Number of skidders in operation.
PDELY Percent of chipper loads requiring sawing. NOTE: Must be three digits in terms of thousandths.
RDIST Skid road/track distance (feet).
REBN1 Time needed to rebunch skid load—mean (centi-minutes).
REBN2 Time needed to rebunch—standard deviation (centi-minutes).
REBUN Percent of single bunches needing rebunching before hauling. NOTE: Must be three digits in terms of thousandths.
ROAD Skid distance along road/track (feet).
SDIST Total skid distance (feet).
SKADD Number of feller/buncher bunches collected into this skid load.
SKBRK Skidder time on break (centi-minutes).
SKBUN Total bunches skidded.
SKGPH Skidder fuel consumption (gallons/hour).
SKHR Total skidder time on job (hours x 100).
SKLND Skidder time spent at landing (centi-minutes).
SNLN Skidder time at landing—nonproductive.
SKTIM Total skidder time—all machines (centi-minutes).
SKTRE Total number of trees skidded.
SKVOL Total volume skidded—all machines.
SPEED Skidder travel speed on road/track (feet/minutes).
TRPAC Trees per acre.

| | |
|---|---|
| VANCY | Van capacity (cubic feet x 100). |
| VNCON | Van contents (cubic feet x 100). |
| VNWT1 | Time needed to replace full van with empty van—mean (centi-minutes). |
| VNWT2 | Time needed to replace van—standard deviation (centi-minutes). |
| WBTU | Btu's in wood per ton. |
| WDIST | Total distance skidders have traveled through the woods (feet). |
| WDTIM | Skid time in the woods (centi-minutes). |
| WKDAY | Length of workday (hours). |

## SWITCHES

| | |
|---|---|
| CBRK | Set by chipper to tell skidders that chipper is on break. |
| CHIPR | Set by chipper to indicate it is on the job. |
| COFFE | Set by timer to indicate coffee break time. |
| DAY | Set by timer to indicate start of shift. |
| EVCPR | Set by vans to indicate empty van available. |
| LUNCH | Set by timer to indicate lunch time. |

## TABLES

| | |
|---|---|
| BNDIA | Total sum of diameter of skid bunch (inches). |
| BNTRE | Number of trees per skid bunch. |
| BNVOL | Volume of skidder loads (cubic feet x 100). |
| CPTIM | Time to chip each load (centi-minutes). |
| CPVOL | Volume in each chip load (cubic feet x 100). |
| SKILN | Time skidder is at landing on each trip (centi-minutes). |
| WDTIM | Time skidder is in woods on each trip (centi-minutes). |

## BOOLEAN VARIABLES

| | |
|---|---|
| ADD | Conditions under which the skidder will add another bunch before skidding to chipper. |
| DROP | Allows skidder to drop trees if there is room at chipper or if chipper is done for the day. |

## VARIABLES

| | |
|---|---|
| ALIGN | Time needed for skidder to align bunch if needed (centi-minutes). |
| BREAK | Time between breaks (centi-minutes). |
| BUCK | Total delay due to bucking logs (centi-minutes). |
| CHIP | Time to chip this load (centi-minutes). |
| CHSAW | Time needed to buck a log (centi-minutes). |
| CLSVN | Time to close full van (centi-minutes). |
| CNPVN | Chipper nonproductive time spent waiting for vans (centi-minutes). |
| CNPWD | Chipper nonproductive time waiting for wood (centi-minutes). |
| CPBRK | Time chipper spends on break (centi-minutes). |
| CPHR | Total chipper time (hours x 100). |
| DROP | Time for skidder to drop bunch (centi-minutes). |
| GRAPL | Skidder-grapple time per bunch (centi-minutes). |
| NGRAP | Number of trees the chipper-grapple takes each load. |
| NIGHT | Remainder of 24 hours after work shift (centi-minutes). |
| NTBUN | Number of trees feller/buncher left in each bunch. |
| RDIST | Skid road/track distance (feet). |
| REBUN | Time needed to rebunch skid load (centi-minutes). |
| RTRAV | Skidder travel time along skid road (centi-minutes). |
| SKBRK | Time skidders spend on break (centi-minutes). |
| SKHR | Total skidder time—all machines (hours x 100). |
| SKNLN | Total nonproductive time for skidders at landing (centi-minutes). |
| SKTIM | Total skid time—all machines (centi-minutes). |
| TVOL | Volume of each tree in terms of d.b.h. (cubic feet x 100). |
| VNWAT | Time needed to change vans (centi-minutes). |
| WDIST | Distance from skid road/trail to bunches (feet). |
| WKDAY | Length of work shift (centi-minutes). |
| WTRAV | Skidder travel time through woods (centi-minutes). |

# APPENDIX B

# PROGRAM LISTING

```
@MTU*GPSSX8.GPSSX8,S ,TPFS,SKDCHP
GPSSX8 V2.6 RL72-8 06/26/81 08:49:39
*- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*
*     SKIDDER CHIPPER SYSTEM SIMULATION      DOCUMENTED 81
*
*       U.S. FOREST SERVICE, NORTH CENTRAL FOREST EXPERIMENT STATION
*       MARKETING PROJECT, DULUTH, MINNESOTA
*       ENGINEERING PROJECT, HOUGHTON, MICHIGAN
*
*    AUTHORS:    DENNIS P. BRADLEY
*                SHARON A. WINSAUER
*
*- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*
*- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*     GENERAL FUNCTIONS NEEDED IN MODEL
*
*- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
*
*
* * * *  FN$SNORM IS USED TO OBTAIN A SAMPLING OF AN APPROXIMATELY
*        NORMAL DISTRIBUTION OF MEAN 0 AND STANDARD DEV 1
*
*        NOTE: TO AVOID DATA LOSS FROM INTEGERIZATION,
*        VALUES HAVE BEEN MULTIPLIED BY 10.
*
*        USE MEAN + ST. DEV*FN$SNORM/10
*
*        NOTE: THE LOWER END OF THE 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
*
*
```

```
    /- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    *
    *                  MASTER TIMER AND REPORT GENERATOR
    *- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    *
    *        THIS SEGMENT CONTROLS THE START AND STOP
    *        OF THE SKIDDERS AND CHIPPERS, THE
    *        HOURS WORKED PER DAY, XSWKDAY, AND
    *        THE NUMBER OF DAYS WORKED
    *        (ARGUMENT A ON THE START CARD) .
    *
    *        IT ALSO CALCULATES THE OUTPUT
    *        VALUES SENT TO HELP BLOCKS.
    *
     WKDAY VARIABLE   X$WKDAY*6000               WORKDAY IN CENTIMINUTES
     NIGHT VARIABLE   (24-X$WKDAY)*6000          REST OF 24 HOURS IN CENTIMINUTES
     BREAK FVARIABLE  V$WKDAY/4                  TIME BETWEEN BREAKS
    *
 1   TIMER GENERATE   ,,,1,12
 2   NXDAY SAVEVALUE  DAYS+,1                    NUMBER OF CURRENT WORKING DAY
 3         LOGIC S    DAY                        TIME TO START WORK
 4         ADVANCE    V$BREAK
 5         LOGIC S    COFFE                      TIME FOR COFFEE BREAK
 6         ADVANCE    V$BREAK
 7         LOGIC S    LUNCH                      LUNCH TIME
 8         ADVANCE    V$BREAK
 9         LOGIC S    COFFE                      TIME FOR TEA
10         ADVANCE    V$BREAK
11         LOGIC R    DAY                        TIME TO QUIT
12         ADVANCE    V$NIGHT
    *
    *
    *
    * * * *  HELP BLOCKS GENERATE REPORT AT END OF EACH 24 HOUR DAY
    *
    *
    * * * * REPORT VARIABLES
    *
     SKTIM VARIABLE   X$WDTIM+X$SKLND            TOTAL SKIDDER TIME (CENTIMINUTES)
     SKHR  VARIABLE   X$SKTIM/60                 TOTAL SKIDDER TIME (HOURS)
    *                                            SKIDDER NON-PRODUCTIVE TIME
     SKBRK FVARIABLE  QC$SKBRK*QT$SKBRK            - ON BREAK
     SKNLN FVARIABLE  QC$CPBUF*QT$CPBUF            - AT LANDING
    *
    *
13         SAVEVALUE  SKTIM,V$SKTIM
14         SAVEVALUE  SKHR,V$SKHR
15         SAVEVALUE  SKBRK,V$SKBRK
16         SAVEVALUE  SKNLN,V$SKNLN
    *
    *
     CPHR  FVARIABLE  X$CPTIM/60                 TOTAL CHIPPER HOURS
    *                                            CHIPPER NON-PRODUCTIVE TIME
     CPBRK FVARIABLE  QC$CPBRK*QT$CPBRK            - ON BREAK
     BUCK  FVARIABLE  QC$CHSAW*QT$CHSAW            - WAITING FOR BUCKING
     CNPWD FVARIABLE  QC$BFEMT*QT$BFEMT            - WAITING FOR WOOD
     CNPVN FVARIABLE  QC$EVCPR*QT$EVCPR            - WAITING FOR VANS
    *
17         SAVEVALUE  CPHR,V$CPHR
18         SAVEVALUE  CPBRK,V$CPBRK
19         SAVEVALUE  BUCK,V$BUCK
20         SAVEVALUE  CNPWD,V$CNPWD
21         SAVEVALUE  CNPVN,V$CNPVN
```

```
            /
            *  *  *  *  STAND DATA AND MACHINE CHARACTERISTICS REPORT
            *
            *                 VOL/ACRE, AVE DBH, TREE HT, TREES/ACRE
      22          HELP           SLSYS,XSAVVOL,XSAVDBH,XSAVHGT,XSTRPAC
            *
            *       NUMBER OF FB, FB TYPE
      23          HELP           SLSYS,XSNUMFB,XSFBTYP
            *
            *       MAX BUNCH SIZE, NUM OF SKID, CHIPPER LOAD MAX
      24          HELP           SLSYS,XSMXSKD,XSNUMSK,XSCMAX
            *
            *       BTU/TON WOOD, WOOD DENSITY, FB FUEL USAGE GAL/TON, FUEL BTU
      25          HELP           SLSYS,XSWBTU,XSLBCFT,XSFBGPT,XSFBTU
            *
            *       SKIDDER HOURS, SKIDDER GALLONS/HOUR, SKIDDED VOLUME
      26          HELP           SLSYS,XSSKHR,XSSKGPH,XSSKVOL
            *
            *       CHIPPER HOURS, CHIPPER GALLONS/HOUR, CHIPPED VOLUME
      27          HELP           SLSYS,XSCPHR,XSCPGPH,XSCPVOL
            *
            *
            *  *  *  *  SKIDDER PRODUCTION REPORT
            *
            *       SKIDDER HOURS, NUMBER OF SKIDDERS, BUNCHES SKIDDED, TREES SKIDDED
      28          HELP           SKIDR,XSSKHR,XSNUMSK,XSSKBUN,XSSKTRE
            *
            *       VOLUME SKIDDED, TOTAL # OF FB BUNCHES, TOTAL SKID DISTANCE
      29          HELP           SKIDR,XSSKVOL,XSSKADD,XSSDIST
            *
            *       WOODS TIME, LANDING TIME, NON-PRODUCTIVE LANDING TIME,BREAK TIME
      30          HELP           SKIDR,XSWDTIM,XSSKLND,XSSKNLN,XSSKBRK
            *
            *       POUNDS/CUFT OF WOOD, SKIDDER GALLONS/HOUR
      31          HELP           SKIDR,XSLBCFT,XSSKGPH
            *
            *
            *  *  *  *  CHIPPER PRODUCTION REPORT
            *
            *       CHIPPER HOURS WORKED, POUNDS/CUFT OF WOOD, NON-PRODUCTIVE TIME
            *       WAITING FOR WOOD, NON-PRODUCTIVE TIME WAITING FOR VANS,
            *       CHIPPER GALLONS/HOUR
      32          HELP           CHIPR,XSCPHR,XSLBCFT,XSCNPWD,XSCNPVN,XSCPGPH
            *
            *       TREES CHIPPED, VOLUME CHIPPED, NUMBER OF FULL VANS, NUMBER OF
            *       CHIPPER LOADS, BUCKING TIME, BREAK TIME
      33          HELP           CHIPR,XSCPTRE,XSCPVOL,XSCPVNS,XSCPLOD,XSBUCK
      34          HELP           CHIPR,XSCPBRK
            *
            *
      35          SPLIT          1,NXDAY
            *
      36    OUTPT TERMINATE  1
```

```
/
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
* * SKIDDER SEGMENT * * *
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
*    THIS SEGMENT MODELS GRAPPLE TYPE SKIDDER(S)
*    SKIDDING BUNCHES PREVIOUSLY LAID DOWN BY A FELLER BUNCHER.
*    THE SKIDDER TRAVELS ALONG A SKID ROAD/TRAIL TO THE WOODS,
*    THEN TRAVELS THROUGH THE WOODS TO GRAPPLE A BUNCH.
*    IT CAN COLLECT MULTIPLE FB BUNCHES BEFORE RETURNING TO
*    THE LANDING.
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
*
* * PARAMETER DEFINITIONS
*
*    P1
*    P2   CLOCK TIME
*    P3   TOTAL NO OF TREES IN BUNCH
*    P4   TOTAL DBH OF BUNCHES COMBINED
*    P5   TOTAL VOL OF BUNCHES COMBINED
*    P6   NUMBER OF BUNCHES GRAPPLED
*    P7   ROAD DISTANCE
*    P8   WOOD DISTANCE
*    P9   NUMBER OF TREES IN NEXT BUNCH
*    P10  COUNTER
*    P11  SUM OF DIA OF NEXT BUNCH
*    P12  TOT VOL OF NEXT BUNCH
*
*
* * DEFINING VARIABLES FOR SKIDDERS
*
    DROP  BVARIABLE  XSNTBUF'LE'XSBUFLM+LRSCHIPR
*                                             TRUE IF ROOM TO DROP TREES
*                                             OR CHIPPER HAS QUIT
*
* * GENERATE SKIDDERS
*
 37 SKDDR GENERATE   ,,,XSNUMSK,8,12
*
*       TIME TO WORK? IF NOT, WAIT
*
 38 START GATE LS    CHIPR                    WAIT UNTIL CHIPPER IS WORKING
 39       MARK       2
 40       ASSIGN     7,VSRDIST                ROAD DISTANCE
 41       QUEUE      RDIST
 42       ADVANCE    VSRTRAV                  TRAVEL TO WOODS
 43       DEPART     RDIST
 44       SAVEVALUE  SDIST+,P7                TOTAL DISTANCE TRAVELED
 45       SAVEVALUE  RDIST+,P7                TOTAL ROAD DISTANCE
*
*         SKIDDER IN WOODS   DETERMINE CHARACTERISTICS OF BUNCH
*
 46 WOODS ASSIGN     9,VSNTBUN                NUMBER OF TREES IN NEXT BUNCH
 47       ASSIGN     10,P9
 48       ASSIGN     8,VSWDIST                WOODS DISTANCE TO BUNCH
*
 49 NDBH  SAVEVALUE  DBH,FNSDBH               FIND SUM OF DIAMETER AND
 50       ASSIGN     11+,XSDBH                TOTAL VOLUME OF NEXT BUNCH
 51       ASSIGN     12+,VSTVOL
 52       LOOP       10,NDBH
```

```
             /      ADD ON FB BUNCH
             *
53                  ASSIGN       3+,P9
54                  ASSIGN       4+,P11
55                  ASSIGN       5+,P12
56                  ASSIGN       6+,1
             *
57                  ASSIGN       9,0
58                  ASSIGN       11,0
59                  ASSIGN       12,0
             *
             *      TRAVEL TO BUNCH AND GRAPPLE IT
             *
60                  QUEUE        WTRAV
61                  ADVANCE      VSWTRAV
62                  DEPART       WTRAV
63                  SAVEVALUE    SDIST+,P8
64                  SAVEVALUE    WDIST+,P8
             *
             *      IF NECESSARY - ALIGN BUNCH
             *
65                  TRANSFER     .XSALIGN,GRAPL,ALIGN
             *
66           ALIGN  QUEUE        ALIGN
67                  ADVANCE      VSALIGN
68                  DEPART       ALIGN
             *
             *      GRAPPLE BUNCH
             *
69           GRAPL  QUEUE        GRAPL
70                  ADVANCE      VSGRAPL
71                  DEPART       GRAPL
             *
             *      TRAVEL TO COLLECTION POINT (ROAD) DIST = P8
             *
72                  QUEUE        WTRAV
73                  ADVANCE      VSWTRAV
74                  DEPART       WTRAV
75                  SAVEVALUE    SDIST+,P8
76                  SAVEVALUE    WDIST+,P8
             *
             *      SHOULD SKIDDER TAKE ANOTHER BUNCH? IS SO RETURN TO WOODS
77                  TEST NE      BVSADD,1,WOODS          IF BVSADD=1 RETURN FOR A BNCH
             *
78                  TEST LE      P6,1,REBUN      MUST REBUNCH IF MORE THAN ONE BUNCH
             *
             *      DOES  SKIDDER NEED TO REBUNCH
             *
             *
79                  TRANSFER     .XSREBUN,SKLND,REBUN
             *
80           REBUN  QUEUE        REBUN                   DROP TREES AND REBUNCH
81                  ADVANCE      VSREBUN
82                  DEPART       REBUN
```

```
                   /
                   *      SKID TO LANDING
                   *
              83    SKLND QUEUE        RDIST
              84          ADVANCE      VSRTRAV
              85          DEPART       RDIST
              86          SAVEVALUE    SDIST+,P7
              87          SAVEVALUE    RDIST+,P7
                   *
                   *      TABULATE  WOODS TIME
                   *
              88          SAVEVALUE    WDTIM+,MP2
                   *
                   *      TABULATE DATA ON BUNCH
              89          TABULATE     WDTIM
              90          TABULATE     BNTRE
              91          TABULATE     BNVOL
              92          TABULATE     BNDIA
                   *
                   *
                   *     SKIDDER AT LANDING
                   *     SKIDDER MUST EITHER DROP LOAD, WAIT FOR ROOM AT CHIPPER TO DROP
                   *     LOAD OR QUIT FOR THE DAY
                   *
              93    LAND  MARK         2                         KEEP TRACK OF LANDING TIME
              94          GATE LS      CBRK,SWORK                IF CHIPPER IS ON BREAK
              95          QUEUE        SKBRK                     SKIDDERS CAN
              96          GATE LR      CBRK                      TAKE BREAK
              97          DEPART       SKBRK
                   *
              98    SWORK QUEUE        CPBUF
              99          TEST E       BVSDROP,1                 WAIT FOR ROOM TO DROP TREES OR
                   *                                             DROP IF CHIPPER HAS QUIT
             100          SEIZE        CPBUF
             101          DEPART       CPBUF
             102          ADVANCE      VSDROP
             103          SAVEVALUE    NTBUF+,P3             ADD THIS LOAD TO CHIPPER BUFFER
             104          RELEASE      CPBUF
                   *
             105          SAVEVALUE    SKLND+,MP2                SKIDDER TIME AT LANDING
                   *
                   *      TABULATE DATA ON BUNCH
             106          TABULATE     SKTLN
             107          SAVEVALUE    SKTRE+,P3
             108          SAVEVALUE    SKVOL+,P5
             109          SAVEVALUE    SKBUN+,1
             110          SAVEVALUE    SKADD+,P6
                   *
                   *
             111          ASSIGN       3,0
             112          ASSIGN       4,0
             113          ASSIGN       5,0
             114          ASSIGN       6,0
             115          ASSIGN       7,0
             116          ASSIGN       8,0
                   *
                   *
             117    WAIT  TRANSFER     ,START
```

```
                    /
                    * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                    *
                    *  *  *  CHIPPER SEGMENT  *  *  *
                    *
                    *      THIS SEGMENT MODELS A CHIPPER WITH A SELF LOADING GRAPPLE
                    *
                    * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
                    *
                    *
                    *                 PARAMETER DEFINITIONS
                    *
                    *      P1         CLOCK TIME
                    *      P2         NUMBER OF TREES IN CHIP-GRAPPLE LOAD
                    *      P3         VOL OF CHIP-GRAPPLE LOAD
                    *      P4         SUM OF DIA OF CHIP-GRAPPLE LOAD
                    *      P5         LOOP COUNTER
                    *
                    *
 118                CHIPR GENERATE    ,,,1,6,6
 119                      LOGIC S     EVCPR                        START WITH A VAN READY
                    *
 120                CSTRT GATE LS     DAY                          TIME TO START WORK ?
 121                      LOGIC S     CHIPR                          CHIPPER IS WORKING
 122                NEWLD MARK        1
 123                      QUEUE       EVCPR
 124                      GATE LS     EVCPR                        SEE IF THERE IS A VAN AVAILABLE
 125                      DEPART      EVCPR
                    *
 126                      QUEUE       BFEMT
 127                      TEST G      XSNTBUF,0                    ARE THERE TREES TO CHIP ?
 128                      DEPART      BFEMT
 129                      ASSIGN      2,VSNGRAP                    NUMBER OF TREES TO GRAPPLE
 130                      TEST L      XSNTBUF,P2,GRAPE             IF GRAPPLE CAN NOT TAKE FULL LOAD
                    *                                              TAKE THOSE AVAILABLE
 131                      ASSIGN      2,XSNTBUF
                    *
                    *     GRAPPLE TREES AND DEFINE SIZE AND VOL
                    *
 132                GRAPE ASSIGN      5,P2
 133                LOAD  SAVEVALUE   DBH,FNSDIAM
 134                      ASSIGN      4+,XSDBH
 135                      ASSIGN      3+,VSTVOL
 136                      LOOP        5,LOAD
                    *
                    *     REMOVE THESE TREES FROM BUFFER AREA AND RESTART SCAN SO WAITING
                    *     SKIDDERS CAN DROP WOOD
                    *
 137                      SAVEVALUE   NTBUF-,P2
 138                      BUFFER
                    *
                    *     XSPDELY - % OF THE TIME THERE IS A DELAY AT THE CHIPPER FOR CHAIN-SAW
                    *     OPERATION
                    *
 139                      TRANSFER    ,XSPDELY,CHIP,CHSAW
                    *
 140                CHSAW QUEUE       CHSAW
 141                      ADVANCE     VSCHSAW                      CHAINSAW DELAY
 142                      DEPART      CHSAW
                    *
 143                CHIP  QUEUE       CHIP
 144                      ADVANCE     VSCHIP                       CHIP LOAD
                          DEPART      CHIP
```

```
                /       RECORD STATISTICS OF CHIPPING
                *
146                     SAVEVALUE  CPTIM+,MP1
147                     TABULATE   CPVOL
148                     TABULATE   CPTIM
149                     SAVEVALUE  CPLOD+,1
150                     SAVEVALUE  CPTRE+,P2
151                     SAVEVALUE  CPVOL+,P3
                *
                *       ADD CHIPPED VOL TO VAN
                *
152                     SAVEVALUE  VNCON+,P3
153                     ASSIGN     2,0
154                     ASSIGN     3,0
155                     ASSIGN     4,0
                *
                *       SEE IF THE VAN IS FULL
                *
156                     TEST GE    XSVNCON,XSVANCY,NEWLD    VAN NOT FULL GET NEW LOAD
                *
                *       VAN IS FULL - ONE TRANSACTION GOES TO CLOSE VAN AND
                *       LINKS IT ON FULL VAN CHAIN TO BE HAULED
                *
                *       THE PARENT TRANSACTION REMAINS THE CHIPPER
                *
157                     LOGIC R    EVCPR
158               FULVN SPLIT      1,LNKVN
159                     MARK       1
160                     QUEUE      CPBRK                    CHECK FOR BREAK TIME
                *
161                     GATE LS    COFFE,NOBRK
162                     LOGIC S    CBRK
163                     ADVANCE    1500                     TAKE BREAK
164                     LOGIC R    COFFE
165                     LOGIC R    CBRK
166               NOBRK GATE LS    LUNCH,CDONE
167                     LOGIC S    CBRK
168                     ADVANCE    3000                     STOP FOR LUNCH
169                     LOGIC R    LUNCH
170                     LOGIC R    CBRK
                *
171               CDONE DEPART     CPBRK                    IS IT END OF SHIFT?
172                     SAVEVALUE  CPTIM+,MP1
173                     GATE LR    DAY,NEWLD                IF NOT END OF DAY GET NEW LOAD
174                     LOGIC R    CHIPR                    CHIPPER DONE FOR TODAY
175                     TRANSFER   ,CSTRT
                *
176               LNKVN SAVEVALUE  VNCON,0
177                     SAVEVALUE  CPVNS+,1
178                     ADVANCE    VSCLSVN                 CLOSE THE VAN
179                     ADVANCE    VSVNWAT                 BRING IN ANOTHER VAN
180                     LOGIC S    EVCPR
181                     TERMINATE
                *
                *
```

```
/
*     *     *    TABLE DEFINITIONS     *     *     *
*
 WDTIM TABLE      MP2,0,50,20             SKIDDER TIME IN WOODS
 SKTLN TABLE      MP2,0,25,20             SKIDDER TIME AT LANDING
*
 BNTRE TABLE      P3,0,2,20               NO. OF TREES PER SKIDDER LOAD
 BNVOL TABLE      P5,0,500,40             VOLUME PER SKID LOAD
 BNDIA TABLE      P4,0,10,30              SUM OF DIAMETER/SKIDDER LOAD
*
 CPVOL TABLE      P3,0,200,30             VOLUME PER CHIPPER LOAD
 CPTIM TABLE      MP1,0,20,30             TIME PER CHIPPER LOAD
*
*
*   *  *  FUNCTION AND VARIABLE DEFINITIONS  *  *  *
*
* * * DEFINING VARIABLES FOR STAND
*
 NTBUN FVARIABLE  FN$NTBUN
 TVOL  FVARIABLE  (133*X$DBH*X$DBH-283)/10  TREE VOL IN TERMS OF DIA
 RDIST FVARIABLE  X$ROAD                  ROAD DISTANCE
 WDIST FVARIABLE  FN$WDIST                WOODS DISTANCE
*
* * * DEFINING VARIABLES FOR SKIDDER
*
 ADD   BVARIABLE  P4'L'X$HALF             IF LESS THAN 1/2 LOAD ADD MORE
 RTRAV FVARIABLE  P7*100/X$SPEED          TRAVEL TIME ON ROAD
 WTRAV FVARIABLE  P8*150/X$SPEED          TRAVEL IN WOODS 2/3 ROAD SPEED
 GRAPL FVARIABLE  X$GRPL1+X$GRPL2*FN$SNORM/10    TIME TO GRAPPLE
 ALIGN FVARIABLE  X$ALGN1+X$ALGN2*FN$SNORM/10    ALIGN BUNCH
 REBUN FVARIABLE  X$REBN1+X$REBN2*FN$SNORM/10
 DROP  FVARIABLE  X$DROP1+X$DROP2*FN$SNORM/10    TIME TO DROP BUNCH
*
* * * *  DEFINING VARIABLES FOR CHIPPER/LOADER
*
 NGRAP FVARIABLE  FN$NGRAP
 CHIP  FVARIABLE  P2*10                          CHIP TIME IN CENTIMIN
 CHSAW FVARIABLE  X$CHSW1+X$CHSW2*FN$SNORM/10
 VNWAT FVARIABLE  X$VNWT1+X$VNWT2*FN$SNORM/10     VAN WAIT TIME
 CLSVN FVARIABLE  X$CLSV1+X$CLSV2*FN$SNORM/10    TIME TO CLOSE VAN
*
*
* * * STAND FUNCTIONS
 NTBUN FUNCTION   RN3,D24                 NUMBER OF TREES PER BUNCH
.004,2/.025,3/.06,4/.09,5/.15,6/.20,7/.24,8/.30,9/.35,10/.39,11/.45,12
.52,13/.58,14/.61,15/.66,16/.70,17/.73,18/.76,19/.80,20/.84,21/.87,22
.91,23/.95,24/1.0,25
*
 WDIST FUNCTION   RN3,C14                 WOODS DISTANCE FOR SKIDDER
.0,0/.23,5/.35,10/.42,15/.53,20/.63,25/.72,30/.77,35/.79,40/.82,45
.86,50/.88,55/.90,60/1.00,100
*
* * * SKIDDER FUNCTIONS
 DBH   FUNCTION   RN4,D7                  TREE DIAMETER INCHES
.05,3/.27,4/.58,5/.82,6/.96,7/.99,8/1.0,9
```

```
/
* * * CHIPPER FUNCTIONS
*
 DIAM  FUNCTION    RN5,D7                TREE DIAMETER FOR CHIPPING
.05,3/.27,4/.58,5/.82,6/.96,7/.99,8/1.0,9
*
 NGRAP FUNCTION    RN3,D10               GRAPPLE LOAD FOR CHIPPER
.12,1/.31,2/.49,3/.66,4/.81,5/.89,6/.95,7/.98,8/.99,10/1.00,12
*
*
*    *    *   INITIAL VALUES FOR THIS RUN    *    *    *
*
      INITIAL    XSWKDAY,8               HRS  IN WKDAY
*
      INITIAL    XSAVHGT,43/XSAVDBH,550  STAND DATA
      INITIAL    XSAVVOL,345000
      INITIAL    XSTRPAC,844
      INITIAL    XSROAD,300              AVE ONE-WAY DISTANCE
      INITIAL    XSLBCFT,65              LB OF  WOOD /CU  FT
      INITIAL    XSWBTU,8000000          BTU   PER TON  OF  WOOD
      INITIAL    XSFBTU,150000           BTU  IN  FUEL PER GAL
*
      INITIAL    XSFBTYP,0/XSNUMFB,1     TRACKED TYPE FELLER BUNCHER
      INITIAL    XSFBGPT,33              FELLER BUNCHER GAL/TON * 100
*
      INITIAL    XSNUMSK,1                       NUMBER OF SKIDDERS
      INITIAL    XSMXSKD,150/XSHALF,85   MAX SKID BUNCH SUM OF DIA
      INITIAL    XSSKGPH,400                     GAL/HRX100
      INITIAL    XSSPEED,352             SKID TRAVEL SPEED FT/MIN
      INITIAL    XSGRPL1,65/XSGRPL2,20           TIME TO POSITION & GRAPPLE
      INITIAL    XSALGN1,50/XSALGN2,30   TIME TO ALIGN BUNCH
      INITIAL    XSALIGN,010                     % OF BUNCHES TO BE ALIGNED
      INITIAL    XSDROP1,30/XSDROP2,15           TIME TO DROP BUNCH
      INITIAL    XSREBN1,50/XSREBN2,25   TIME TO REBUNCH
      INITIAL    XSREBUN,150                     % OF TIME HE REBUNCHES 1 LOAD
*
      INITIAL    XSBUFLM,50        LIMIT - TREES AT CHIPPER
*
      INITIAL    XSCMAX,12               MAX CHIPPER LOAD
      INITIAL    XSCPGPH,570             LARGE CHIPPER GAL/HR.
      INITIAL    XSCHSW1,47/XSCHSW2,9    CHAIN SAW DELAY TIME
      INITIAL    XSPDELY,050
*
      INITIAL    XSVANCY,100000
      INITIAL    XSCLSV1,100                     CLOSE VAN TIME
      INITIAL    XSVNWT1,400                     VAN WAIT TIME
*
      RMULT      ,,,17,17
      START      5,,5,1
      END
```

```
      SUBROUTINE SLSYS(IX)
      DIMENSION IX(5)
      DATA I/0/
      REAL MXSKD
C
    1 FORMAT(1H1,54X,'SAWLOG  SORTING  '
     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'/1H ,29X, 'FOREST  PRODUCTS  MARKETING  AND  U
     DTILIZATION  PROJECT,  DULUTH,  MINNESOTA'/1H ,61X,'AND  THE'/1H,40
     EX,'FOREST  ENGINEERING  LABORATORY, HOUGHTON,  MICHIGAN'/1H ,62X,
     F'AUTHORS '/1H ,52X,'DENNIS P. BRADLEY, ECONOMIST'/1H ,51X,'SHARON
     GA. WINSAUER, PROGRAMMER'/)
C
    2 FORMAT(1H0,'I.  STAND CHARACTERISTICS.',/
     A                                1H0,F12.2,' CUFT., 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-BUNCHERS.',10X ,I10,'  MACHINE(S)',
     B5X,'TRACKED TYPE')
C
    4 FORMAT(1H0,'II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ',
     A'ANALYST.'//1H ,2X,'A.  FELLER-BUNCHERS.',10X ,I10,'  MACHINE(S)',
     B5X,'RUBBER-TIRED TYPE',//)
C
C
    8 FORMAT(
     A /1H0,'  B.  SKIDDERS.',10X  ,I10,'  MACHINE(S)',5X,'RUBBER',
     A'-TIRED GRAPPLE SKIDDER(S). ',//)
C
    9 FORMAT(1H,8X,'MAXIMUM SKID BUNCH HAS TOTAL SUM OF '
     A'DIAMETER',F8.2,' INCHES'//)
C
   11 FORMAT(1H0,'  C.  CHIPPER-LOADER.',//1H,8X,'THE LOADER',
     A' CAN TAKE A LOAD OF ',F5.0,'TREES')
C
C
   13 FORMAT(1H,6X,'ENERGY BALANCE',//,12X,F6.2,' GAL/TON - ',
     A'FELLER BUNCHER',//,12X,F6.2,' GAL/TON - SKIDDER',//,
     B12X,F6.2,' GAL/TON - CHIPPER',//,11X,F7.2,' TOTAL GAL/TON ',
     C'@',F10.2,' BTU/GAL',///)
C
   14 FORMAT(1H,7X,F10.2,' BTU/TON USED AS FUEL',//,8X,F10.2,
     A' BTU/TON HARVESTED FROM WOOD',///,
     B9X,F9.2,5X,'ENERGY BENEFIT RATIO.')
C
      X1 = IX(1)
      X2 = IX(2)
      X3 = IX(3)
      X4 = IX(4)
      X5 = IX(5)
      I = I + 1
      IF ( I .GT. 6 ) I = 1
      GO TO (10,20,30,40,50,60),I
C
   10 CONTINUE
      AVVOL= X1/100.
C AVVOL = AVERAGE VOLUMN PER ACRE - CUFT.
      AVDBH= X2/100.
C AVDBH = 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=X1
C NUMFB = NUMBER OF FELLER-BUNCHERS
      FBTYP=X2
C  FBTYP  FELLER BUNCHER TYPE  0 = DROTT  1 = RUBBER-TIRED TYPE
      IF(FBTYP.EQ.0)WRITE(6,3)NUMFB
      IF(FBTYP.EQ.1)WRITE(6,4)NUMFB
      RETURN
C
   30 CONTINUE
      MXSKD  = X1
C   MXSKD    MAXIMUM SUM OF DIAMETER PER BUNCH
      NUMSK=X2
C NUMSK = NUMBER OF SKIDDERS
      WRITE(6,8) NUMSK
      WRITE(6,9) MXSKD
      XLODLM = X3
C  CHIPPER LOAD LIMIT
      WRITE(6,11)XLODLM
      RETURN
C
   40 CONTINUE
      WBTU=X1
C  BTU PER TON OF WOOD
      XDEN=X2
C  LBS OF WOOD PER CU. FT.
      FBGPT = X3/100
      FBTU=X4
      RETURN
C
   50 CONTINUE
C  HOURS SKIDDER WORKED
      SKHR = X1/100.
      SKGPH = X2/100
C  SKIDDER FUEL CONSUMPTION - GAL/HOUR
      SKTNS = X3*XDEN/200000
C  SKIDDER PRODUCTION IN TONS
      RETURN
C
   60 CONTINUE
      CPHR = X1/100.
C  HOURS CHIPPER WORKED
      CPGPH = X2/100
C  CHIPPER FUEL CONSUMPTION - GAL/HOUR
      CPTNS = X3*XDEN/200000
C  CHIPPER PRODUCTION IN TONS
C  CALCULATE TOTAL FUEL CONSUMPTION
      SKTFC = SKHR * SKGPH
      CPTFC = CPHR * CPGPH
      SKGPT = SKTFC/SKTNS
      CPGPT = CPTFC/CPTNS
      TGPT = FBGPT+SKGPT+CPGPT
      TONS = SKTNS
C  TOTAL TONS COMPLETE
C  CHANGE TO CPIR TONS WHEN ADDED
      FBTFC = FBGPT*TONS
      SKTFC = SKGPT*TONS
      CPTFC = CPGPT*TONS
      TFC = FBTFC+SKTFC+CPTFC
C  CALCULATE GALLONS OF FUEL PER TON
C BTU PER TON USED AS FUEL
      BTUTF = TGPT * FBTU
C  ENERTY BENEDIT RATIO
      EBC = WBTU/BTUTF
C
C
      WRITE(6,13)FBGPT,SKGPT,CPGPT,TGPT
C
      WRITE(6,14)BTUTF,WBTU,EBC
      RETURN
      END
```

```
      SUBROUTINE SKIDR (IX)
      DIMENSION IX(5)
      DATA I/0/
      REAL  SKTNS
      INTEGER SKDIS,SKBUN,SKTRE
C
C
    1 FORMAT(1H1,9X,'S K I D D I N G   P R O D U C T I O N   A N D',
     A'   C O S T   S U M M A R Y  '/////,1H,132('*'),//,1H,'I.     A.',
     BF8.2,5X,'HOURS WORKED BY SKIDDER(S).',//,1H,6X,'B.',I5,8X,
     C'NUMBER OF SKIDDER(S).',//
     D                                1H ,'II.    A.',I5,8X,'BUNCHES ',
     E'SKIDDED - ALL MACHINES.',/)
C
    2 FORMAT(1H,15X,F8.2,5X,'AVERAGE NUMBER OF FELLER-BUNCHER BUNCHES',
     A' COLLECTED.',//,16X,F8.2,5X,'AVERAGE NUMBER OF TREES PER',
     B' SKIDDER BUNCH.',//,
     C7X,'B.',I5,8X,'TREES SKIDDED - ALL MACHINES.',//,7X,'C.',
     DF8.2,5X,'VOLUME SKIDDED - CU.FT. - ALL MACHINES.',//,7X,'D.',
     E  I8,5X,'TOTAL DISTANCE SKIDDED.',//,7X,'E.',
     FF8.2,5X,'TOTAL TONS SKIDDED - ALL MACHINES.',///)
C
    3 FORMAT(1H,'III.   A.',F8.2,5X,'BUNCHES SKIDDED PER MACHINE ',
     A'HOUR.',//,7X,'B.',F8.2,5X,'TREES SKIDDED PER MACHINE HOUR.',//,
     B7X,'C.',F8.2,5X,'VOL. SKIDDED PER MACHINE HOUR - CU.FT.',
     C//,7X,'D.',F8.2,5X,'TONS SKIDDED PER MACHINE HOUR.'/)
C
    4 FORMAT(1H,'IV.    A.',F8.2,5X,'AVERAGE ONE-WAY SKID DISTANCE ',
     A'PER TRIP - FEET.',//,7X,'B.',F8.2,5X,'AVERAGE ROUND TRIP ',
     B'TIME IN MINUTES - ALL ACTIVITIES.',//,     16X,F8.2,5X,
     C          'TIME - LANDING TO WOODS AND RETURN.',//,16X,
     DF8.2,5X,'PRODUCTIVE TIME - LANDING ACTIVITY.',//,
     F      16X,F8.2,5X,'NON-PRODUCTIVE TIME-WAITING TO DROP AT CHIPPER.',
     G  //1H ,15X,F8.2,5X,'TIME ON BREAKS'/)
C
C
    6 FORMAT(1H,'V.     A.',F8.2,5X,'TOTAL GALLONS USED.',//,16X,
     A   F8.2,5X,'GALLONS PER HOUR.',//,          16X,F8.2,5X,'GALLONS',
     B' PER TON.')
C
      X1 = IX(1)
      X2 = IX(2)
      X3 = IX(3)
      X4 = IX(4)
      X5 = IX(5)
C
      I = I+ 1
      IF ( I .GT. 4) I = 1
      GO TO ( 10,20,30,40 ),I
C
   10 CONTINUE
      SKHR = X1/100.
      NUMSK = X2
C NUMSK = NUMBER OF SKIDDERS
      SKBUN = X3
C SKBUN = BUNCHES SKIDDED, ALL MACHINES
      SKTRE = X4
C SKTRE = TREES SKIDDED, ALL MACHINES
      RETURN
C
```

```
   20 CONTINUE
      SKVOL = X1/100.
C SKVOL = VOL. SKIDDED -CUFT. -ALL MACHINES
      BNTOT = X2
C  TOTAL NUMBER OF FELLER-BUNCHER BUNCHES.
      SKDIS = X3
C SKDIS = DISTANCE SKIDDED -FEET PER ROUND TRIP -ALL MACHINES
      BNAVE = BNTOT/SKBUN
C  BNAVE  THE AVE. # OF FELLER BUNCHER BUNCHES COLLECTED
      RETURN
C
   30 CONTINUE
      SKPWL = X1 /( 100.*SKBUN)
C SKPWL = PRODUCTIVE TIME - LANDING TO WOODS AND RETURN
      SKLND = X2/(100.*SKBUN)
      SKNLN = X3 /( 100.*SKBUN)
C SKNLN = NON-PRODUCTIVE TIME - WAITING TO DROP THE BUNCH AT THE CHIPPER
C SKBRK = TIME ON BREAKS
      SKBRK = X4/(100.*SKBUN)
      SKPLN = SKLND - SKNLN - SKBRK
      RETURN
C
   40 CONTINUE
      LBCFT = X1
C  LBCFT   POUNDS PER CUBIC FOOT OF WOOD
      SKGPH = X2/100
C  SKGPH   SKIDDER  GALLONS/HOUR
C
      SKTPB = SKTRE*1./SKBUN
C   SKTPB    TREES PER BUNCH
      WRITE(6,1)SKHR,NUMSK,SKBUN
C
      SKTNS = (SKVOL*LBCFT)/2000.
C   SKTNS    TOTAL TONS SKIDDED
        SKBMH = SKBUN/SKHR
C SKBMH = BUNCHES SKIDDED PER MACHINE HOUR
      SKTMH = SKTRE/SKHR
C SKTMH = TREES SKIDDED PER MACHINE HOUR
      WRITE(6,2)BNAVE,SKTPB,SKTRE,SKVOL,SKDIS,SKTNS
C
C
      SKVMH = SKVOL/SKHR
C SKVMH = VOL. SKIDDED PER MACHINE HOUR
      SKTNH = SKTNS/SKHR
C   SKTNH    TONS SKIDDED PER MACHINE HOUR
      SKADS = SKDIS*1./(2.*SKBUN)
C SKADS = AVERAGE ONE-WAY SKID DISTANCE PER TRIP - FEET
      SKTMA = SKHR*60/SKBUN
C SKTMA = AVERAGE ROUND TRIP TIME IN MINUTES - ALL ACTIVITIES
      WRITE(6,3)SKBMH,SKTMH,SKVMH,SKTNH
C
      WRITE(6,4)SKADS,SKTMA,SKPWL,SKPLN,SKNLN,SKBRK
C
C
C
      SKTGU = SKGPH*SKHR
C   SKTGU    TOTAL GALLONS USED
      SKGPT = SKTGU/SKTNS
C   SKGPT    GALLOMS PER TON
      WRITE(6,6)SKTGU,SKGPH,SKGPT
      RETURN
      END
```

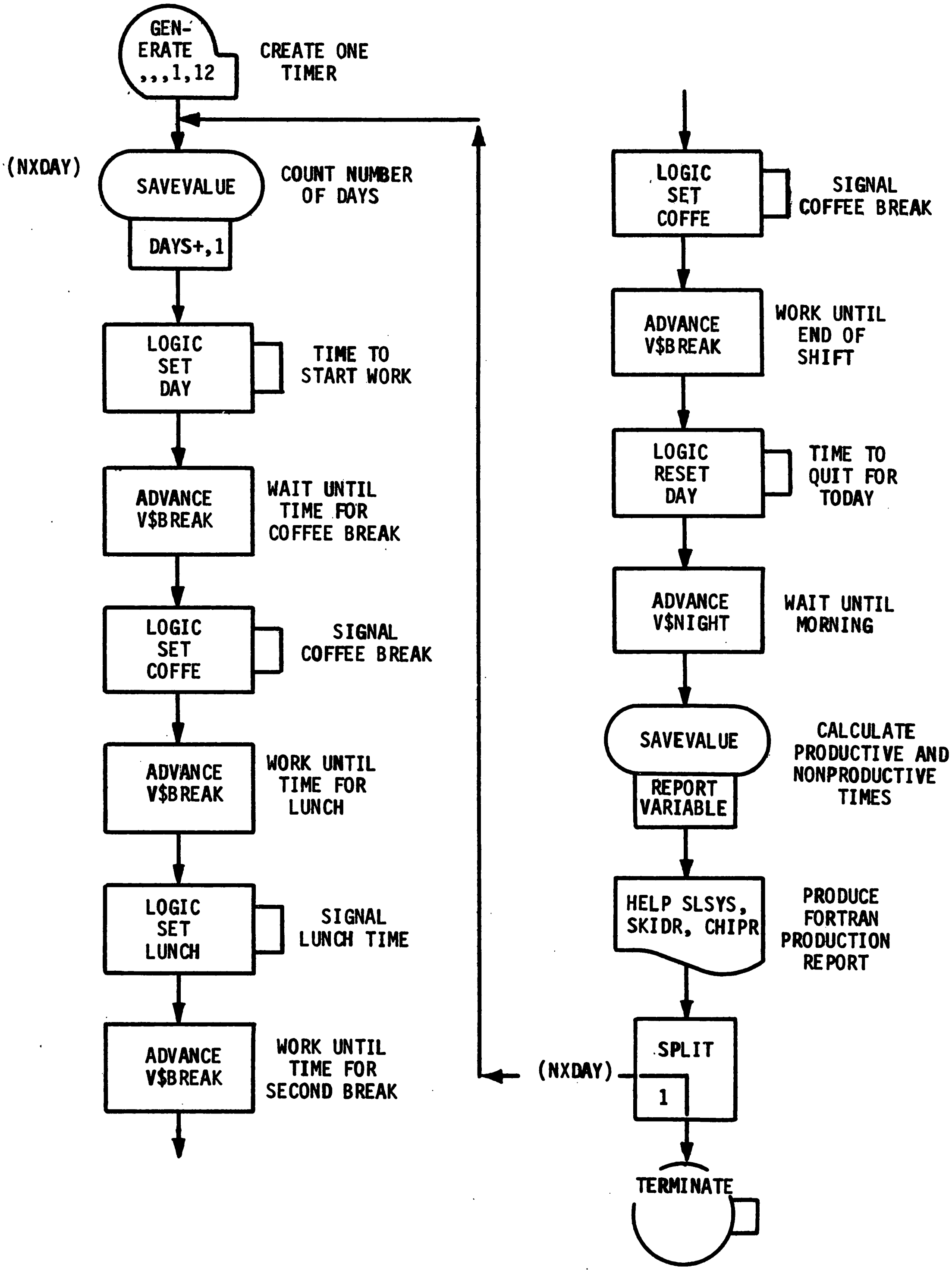
```
      SUBROUTINE CHIPR (IX)
      DIMENSION IX(5)
      INTEGER         CPLOD
      INTEGER CPTRE,CPVNS
C
    1 FORMAT(1H1,9X,'C H I P P E R - L O A D E R   P R O D U C T ',
     A'I O N   A N D   C O S T   S U M M A R Y ',//,1H,132('*'),///
     B///,1H,'I.     A.',F8.2,5X,'HOURS WORKED BY CHIPPER-LOADER.',
     C                  ///,1H,'II.     A.',I5,8X,'LOADS CHIPPED.',//,1H,
     E      15X,F8.2,5X,'AVERAGE NUMBER OF STEMS PER LOAD.',//,1H,
     F 15X,F8.2,5X,'AVERAGE VOLUME PER LOAD - CU.FT.',/)
C
    2 FORMAT(1H,    6X,'B.',I8,5X,'TREES CHIPPED.',//,7X,'C.',F8.2,
     A5X,'VOLUME CHIPPED - CU.FT.',//,7X,'D.',F8.2,5X,'TONS CHIP',
     B'PED.',//,7X,'E.',I8,5X,'VANS FILLED.',//,          16X,F8.2,5X,
     C'AVERAGE NUMBER OF LOADS PER VAN.',//,       16X,F8.2,5X,
     D'AVERAGE VOLUME PER VAN - CU.FT.',//,      16X,F8.2,5X,
     E'AVERAGE TONS PER VAN.',///)
C
    3 FORMAT(1H,'III.    A.',F8.2,5X,'LOADS CHIPPED PER MACHINE HOUR.',
     A//,7X,'B.',F8.2,5X,'TREES CHIPPED PER MACHINE HOUR.',//,7X,
     B'C.',F8.2,5X,'VOLUME CHIPPED PER MACHINE HOUR - CU.FT.',//,
     C7X,'D.',F8.2,5X,'TONS CHIPPED PER MACHINE HOUR.',//,
     D7X,'E.',F8.2,5X,'VANS FILLED PER MACHINE HOUR.',///)
C
    4 FORMAT(1H,'IV.    A.',F8.2,5X,'AVERAGE CHIPPING TIME PER VAN',
     A' FILLED - ALL ACTIVITIES - MINUTES.',//,          16X,F8.2,5X,
     B'PRODUCTIVE TIME PER VAN - MINUTES.',//,          16X,F8.2,5X,
     C'NON-PRODUCTIVE TIME PER VAN - DUE TO EXTERNAL EVENTS - MIN',
     D'UTES.',//,          23X,F8.2,5X,'LOADER WAITING FOR WOOD FROM',
     E' SKIDDERS - MINUTES.',//,          23X,F8.2,5X,'CHIPPER WAIT',
     F'ING FOR VANS TO FILL - MINUTES.',//1H ,22X,F8.2,5X,
     G  'BUCKING TIME'//1H ,22X,F8.2,5X,'BREAK TIME'///)
C
C
    6 FORMAT(1H,'VI.    A.',F8.2,5X,'TOTAL GALLONS OF FUEL USED.',
     A//,          16X,F8.2,5X,'GALLONS/HOUR.',//,          16X,F8.2,
     B5X,'GALLONS/TON.')
C
        X1 = IX(1)
        X2 = IX(2)
        X3 = IX(3)
        X4 = IX(4)
        X5 = IX(5)
C
      I = I+ 1
      IF ( I .GT. 3 ) I = 1
      GO TO ( 10,20,30 ) , I
C
   10 CONTINUE
      CPHR = X1/100.
      LBCFT = X2
C   LBCFT   POUNDS OF WOOD PER CUBIC FOOT
      CNPWD = X3/100.
C CNPWD = LOADER WAITING FOR WOOD FROM SKIDDER
      CNPVN = X4/100.
C CNPVN  = CHIPPER WIATING FOR VAN FROM TRUCKS
      CPGPH = X5/100.
C   CPGPH   CHIPPER-LOADER GALLONS PER HOUR
      RETURN
```

```
C
   20 CONTINUE
      CPTRE = X1
C CPTRE = TREES CHIPPED
      CPVOL = X2/100.
C CPVOL = VOLUME CHIPPED, CUFT.
       CPVNS = X3
C CPVNS = VANS FILLED
      CPLOD = X4
C CPLOD = LOADS CHIPPED
      BUCK = X5/100
C BUCK = BUCKING TIME
      RETURN
C
   30 CONTINUE
      CPBRK = X1/100
C CPBRK = BREAK TIME
C
      CPSPL = CPTRE*1./CPLOD
C CPSPL = AVERAGE NUMBER OF STEMS PER LOAD
      CPVPL = CPVOL/CPLOD
C CPVPL = AVERAGE VOLUME PER LOAD, CUFT.
      WRITE (6 ,1)        CPHR,          CPLOD,CPSPL,CPVPL
      CPTNS = (CPVOL*LBCFT)/2000.
C   CPTNS    TOTAL TONS CHIPPED
C
      CPLPV = CPLOD*1./CPVNS
C CPLPV = AVERAGE NUMBER OF LOADS PER VAN
      CPVPV = CPVOL/CPVNS
C CPVPV = AVERAGE VOLUME PER VAN, CUFT.
      CPTPV = CPTNS/CPVNS
C   CPTPV    TONS PER VAN
      WRITE(6,2)CPTRE,CPVOL,CPTNS,CPVNS,CPLPV,CPVPV,CPTPV
C
      CPLMH = CPLOD/CPHR
C CPLMH = LOADS CHIPPED PER MACHINE HOUR
      CPTMH = CPTRE/CPHR
C CPTMH = TREES CHIPPED PER MACHINE HOUR
      CPVLH = CPVOL/CPHR
C CPVLH = VOLUME CHIPPED PER MACHINE HOUR, CUFT.
      CPVNH = CPVNS/CPHR
C CPVNH = VANS FILLED PER MACHINE HOUR
      CPTNH = CPTNS/CPHR
C   CPTNH    TONS CHIPPED PER MACHINE HOUR
      CPACT = CPHR *60/CPVNS
C CPACT = AVERAGE CHIPPING TIME PER VAN FILLED - ALL ACTIVITIES -MINUTES
      WRITE(6,3)CPLMH,CPTMH,CPVLH,CPTNH,CPVNH
C
      CPNPT =(CNPWD + CNPVN + BUCK + CPBRK)/CPVNS
C CPNPT = NON PRODUCTIVE CHIPPERN TIME
      CPPTM = CPACT-CPNPT
C CPPTM = PRODUCTIVE TIME PER VAN - MINUTES
      CNPWD = CNPWD/CPVNS
      CNPVN  = CNPVN/CPVNS
      BUCK = BUCK/CPVNS
      CPBRK = CPBRK/CPVNS
      WRITE(6,4)CPACT,CPPTM,CPNPT,CNPWD,CNPVN,BUCK,CPBRK
C
C
      CPTGU = CPHR*CPGPH
C   CPTGU    TOTAL GALLONS USED
      CPGPT = CPGPH/CPTNH
C   CPGPT    GALLONS PER TON
       WRITE(6,6)CPTGU,CPGPH,CPGPT
      RETURN
      END
```

# APPENDIX C
# COMPLETE FLOW CHARTS

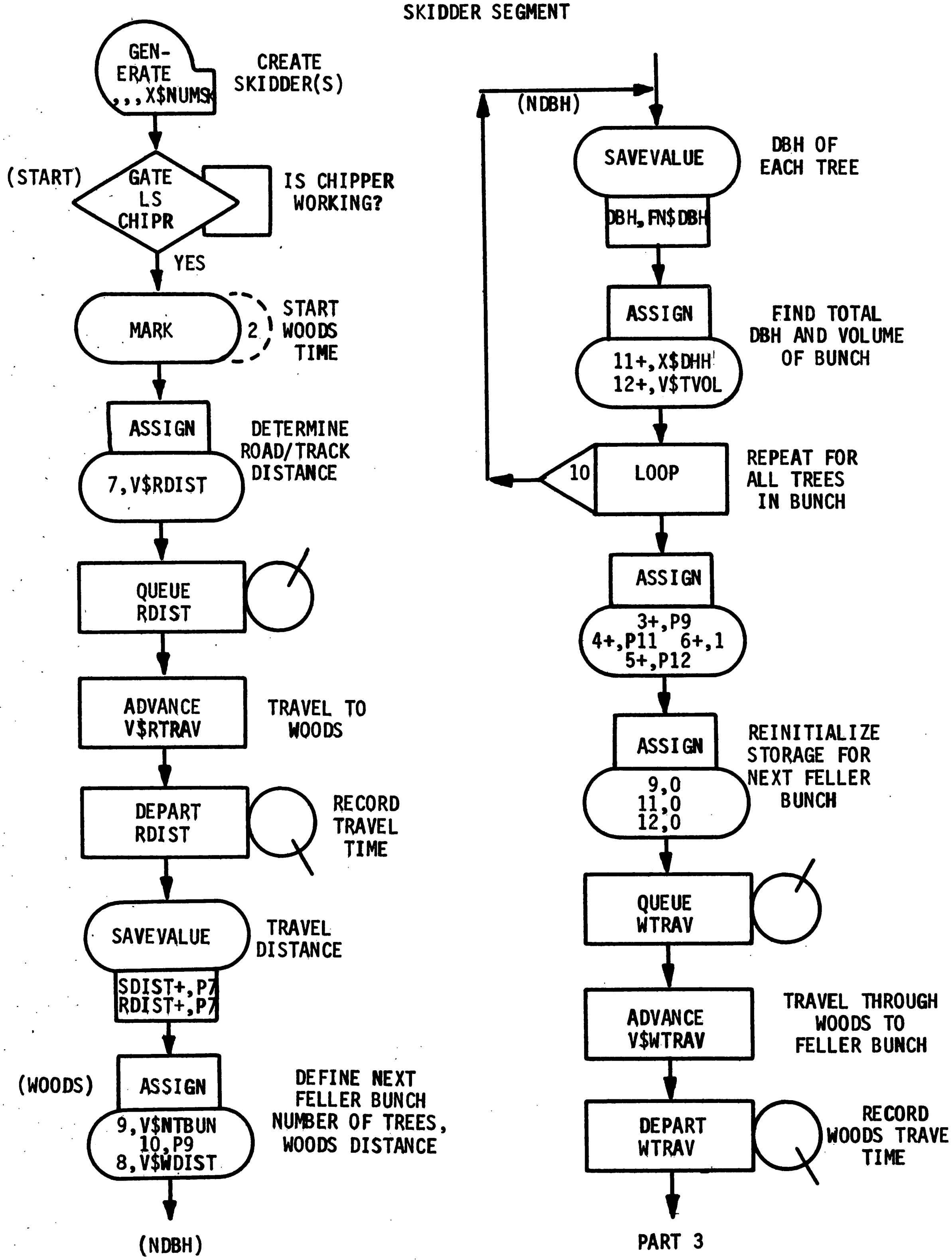
COMPLETE FLOW CHARTS - PART 1 OF 7

TIMER SEGMENT



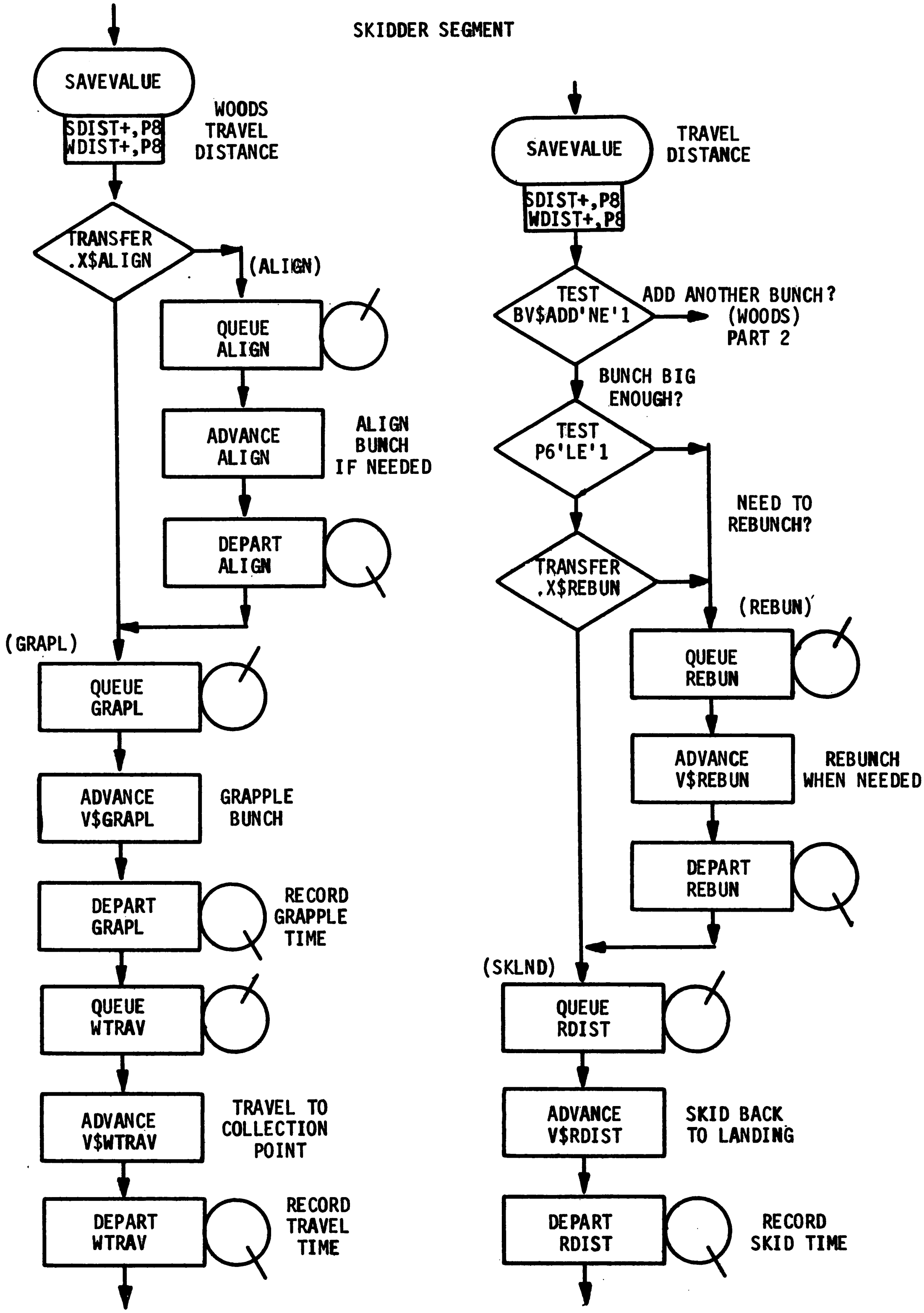
COMPLETE FLOW CHARTS - PART 2 OF 7

SKIDDER SEGMENT



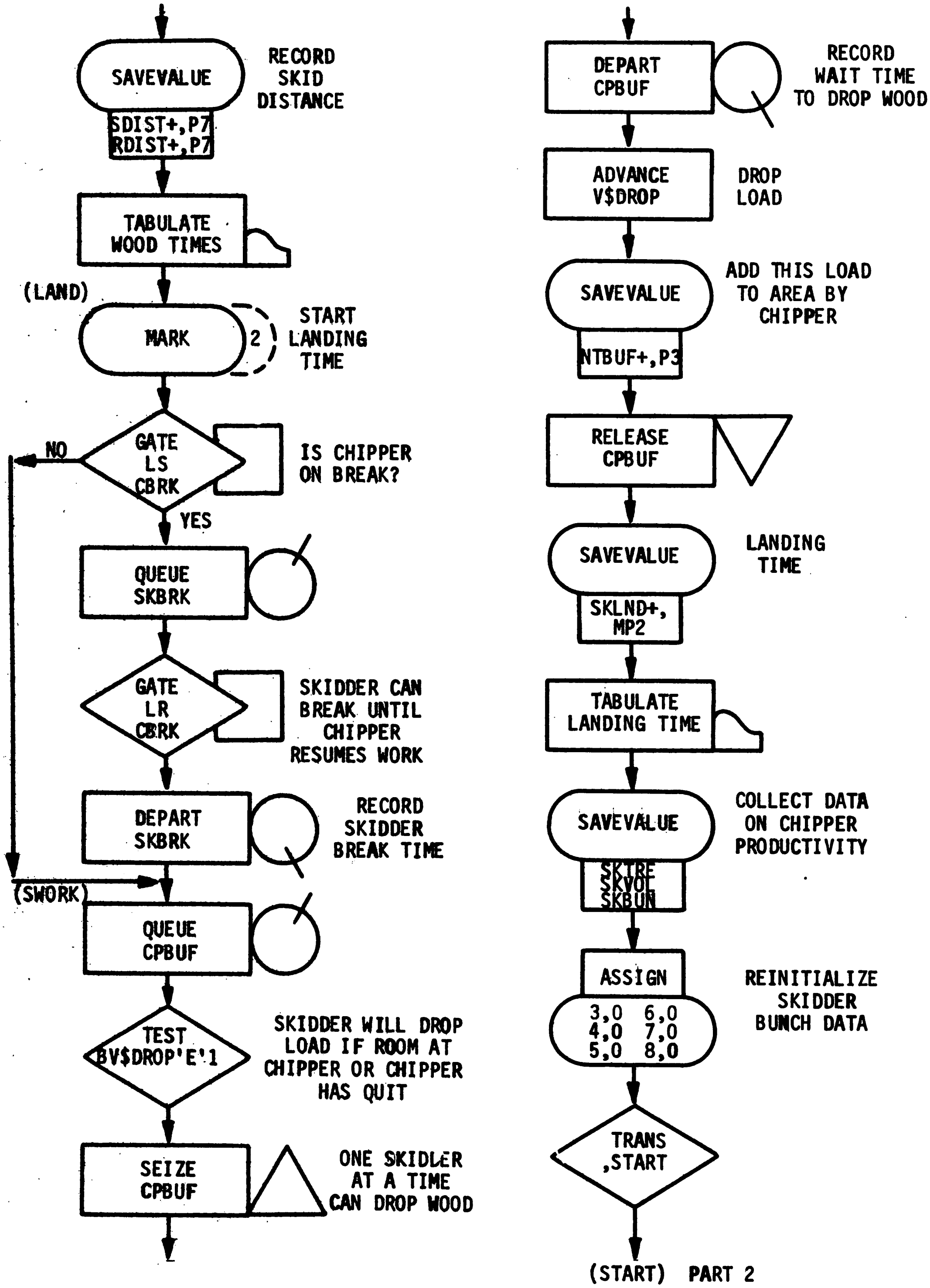
COMPLETE FLOW CHARTS - PART 3 OF 7

SKIDDER SEGMENT



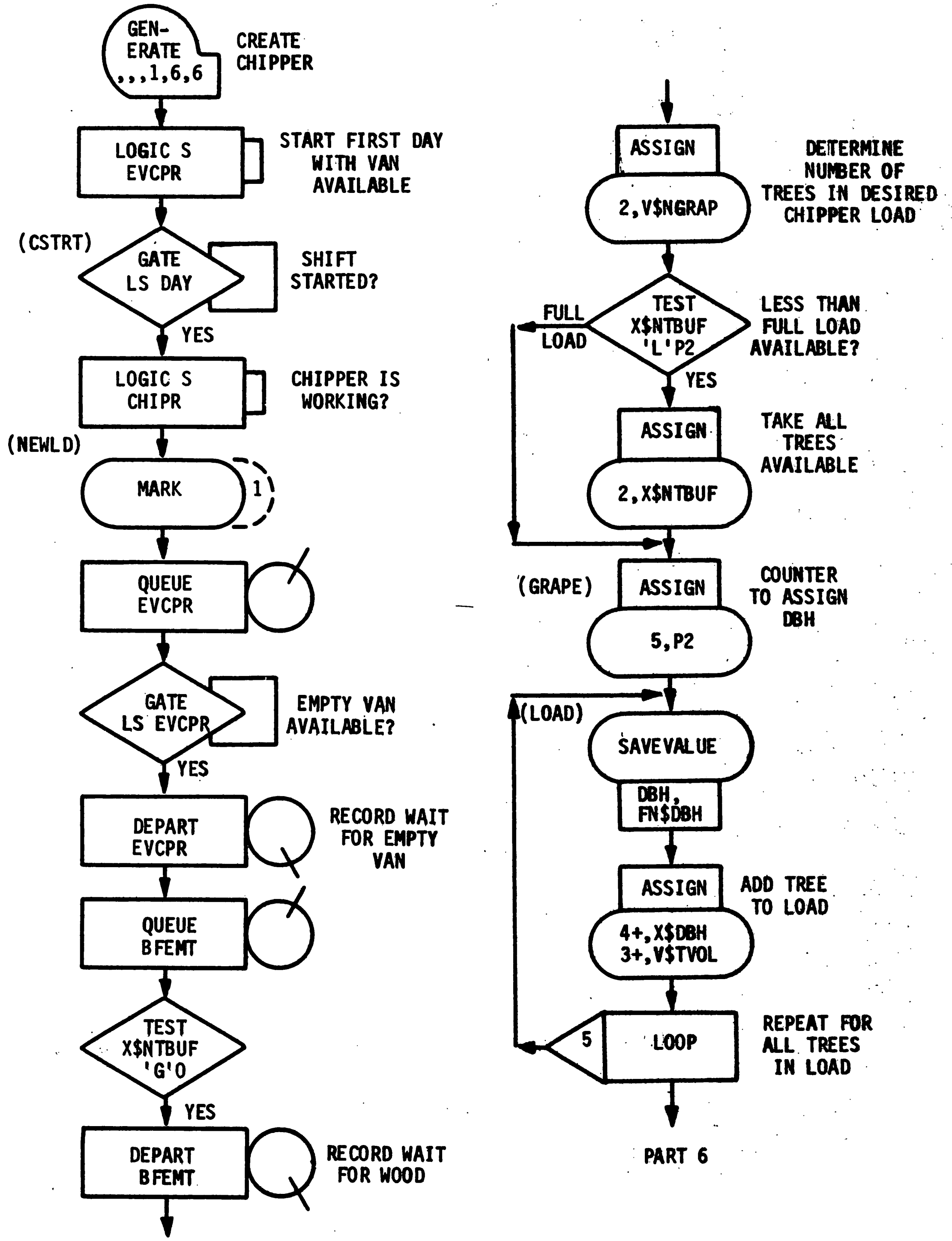
COMPOETE FLOW CHARTS - PART 4 OF 7

SKIDDER SEGMENT



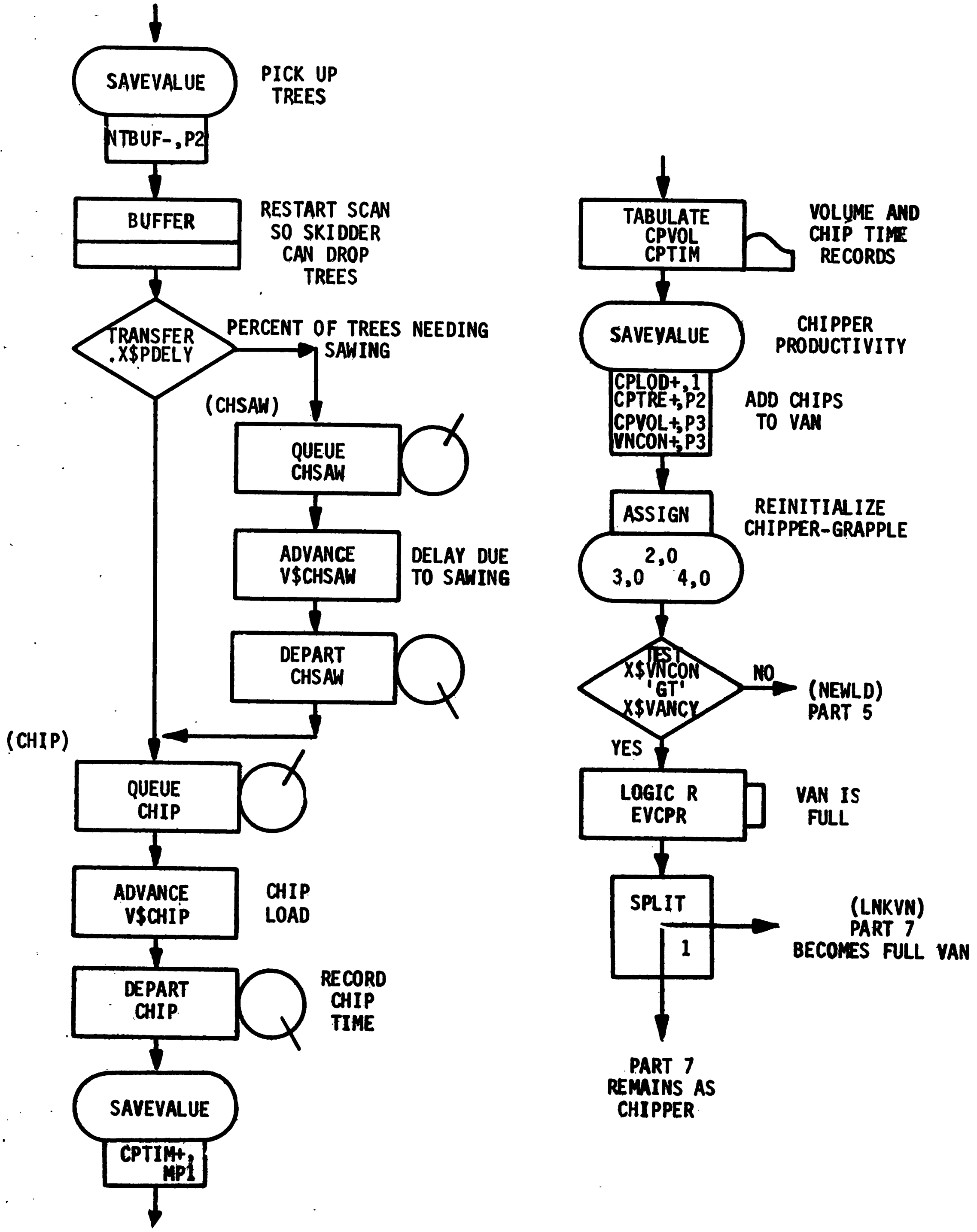
COMPLETE FLOW CHARTS - PART 5 OF 7

CHIPPER SEGMENT



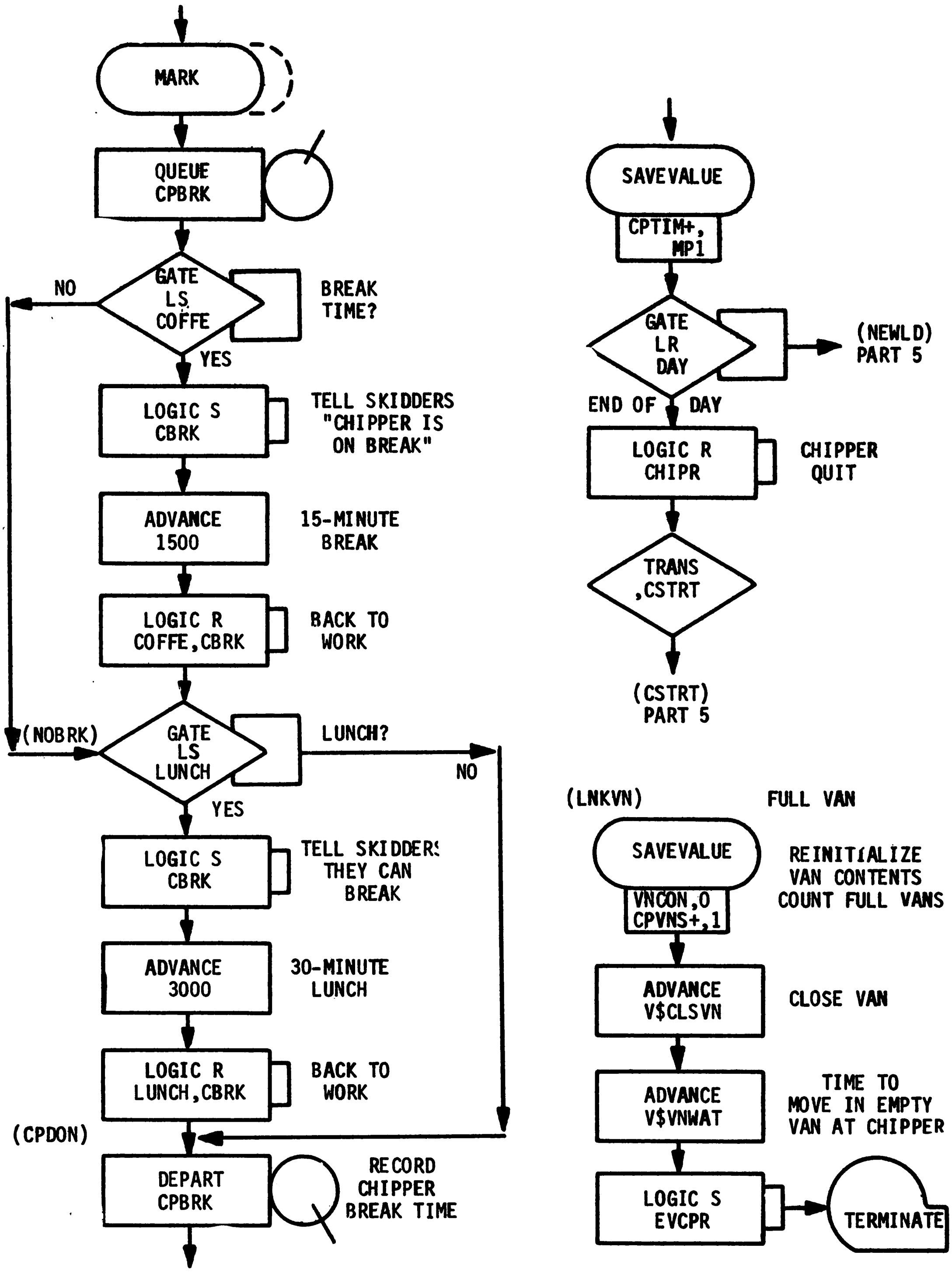
COMPLETE FLOW CHARTS - PART 6 OF 7

CHIPPER SEGMENT



COMPLETE FLOW CHARTS - PART 7 OF 7

CHIPPER SEGMENT

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Winsauer, Sharon A.
A program and documentation for simulation of grapple skidders and a whole-tree chipper. Res. Pap. NC-221. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1982. 42 p.

Presents a computer model written in GPSS (General Purpose Simulation System) designed to simulate a skidding-chipping operation.

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