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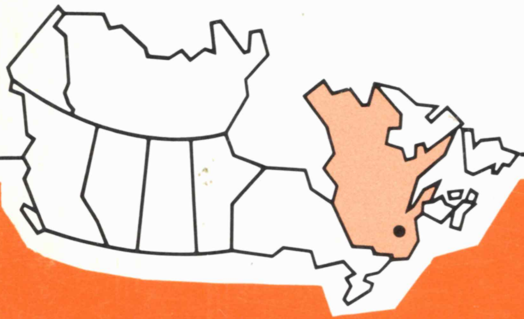
Forest biomass harvesting simulation model

Jean-Guy Routhier
Darveau, Grenier, Lussier and Associates
ENFOR Project P-237

Information Report LAU-X-53E

Laurentian Forest Research Centre



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LAURENTIAN FOREST RESEARCH CENTRE
CANADIAN FORESTRY SERVICE

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FOREWORD

ENFOR is the bilingual acronym for the Canadian Forestry Service's ENergy from the FORest (ENergie de la FORêt) program of research and development aimed at securing the knowledge and technical competence to facilitate, in the medium- to long-term, a greatly increased contribution from forest biomass to our nation's primary energy production. This program is part of a much larger federal government initiative to promote the development and use of renewable energy as a means of reducing our dependence on pretroleum and other non-renewable energy sources.

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ENFOR Secretariat
Canadian Forestry Service
Ottawa, Ontario
K1A 1G5

or the director of the establishment from which this report originates.

This report, based on ENFOR Project P-237, was prepared by Jean-Guy Routhier, F.e., M.e.s., pursuant to the mandate conferred on the firm of Darveau, Grenier, Lussier and Associates (DSS file 11-SD-KH-303-1-C-023).

The investigations conducted in the course of this study resulted in the development of a simulation model designed as a simple, efficient tool for planning and co-ordinating, in the most economical possible way, forest biomass harvesting operations on small privately owned woodlots in Quebec.

ABSTRACT

Forest biomass harvesting, in the context of private forests, is usually carried out in dense, young stands comprising stems whose diameter at breast height varies from 2 to 10 or 12 cm. Little expertise available in the harvesting of those stands led to the design and the construction of a simulation model to identify and develop efficient forest biomass harvesting systems.

This report presents the simulation model developed for this specific purpose. The use of the model is clearly described, the required data to carry out a simulation are identified, and the results obtained through simulation are explained. As the test goes, different situations are presented where simulation may be used to forecast and improve harvesting productivity and costs. In the last part of the report, an example of a chip harvesting simulation for biomass is presented, along with a discussion of results.

RÉSUMÉ

L'exploitation de la biomasse forestière, dans le cadre de la forêt privée, a généralement lieu dans de jeunes peuplements denses composés en majorité de tiges dont le diamètre à hauteur de poitrine varie de 2 à 10 ou 12 cm. Le peu d'expertise dans l'exploitation de ces peuplements a suscité la conception et la réalisation d'un modèle permettant de simuler l'exploitation de la biomasse sur ordinateur afin d'identifier et de hâter le développement de systèmes d'exploitation efficaces.

Ce rapport présente le modèle de simulation conçu à cette fin. Il décrit la façon d'utiliser le modèle, précise les données requises pour réaliser une simulation et explique les résultats obtenus. Tout au long du texte, on présente diverses situations où la simulation peut être utilisée pour prévoir ou améliorer la productivité et les coûts d'une exploitation. En dernier lieu, un exemple de la simulation d'une opération de mise en copeaux de la biomasse est présenté, accompagné d'une discussion des résultats obtenus.

June 29, 1982

Dr. Gilles Frisque, F.e.
Laurentian Forest Research Centre
1080 route du Vallon
Sainte-Foy, Quebec
G1V 4C7

Dear Dr. Frisque:

Please find enclosed the original and required copies of a report titled "Forest Biomass Harvesting Simulation Model" with regard to ENFOR Project P-237 (DSS contract 11SD.KH 303-1-C-023).

As you will find upon reading the report, the simulation model is very flexible and convenient to use. It provides for productivity and cost analysis of the machines that form part of a forest biomass harvesting system. The report deals with many different situations amenable to simulation analysis and presents the simulation of a biomass chipping operation by way of example.

Yours truly,

(SGD) DARVEAU, GRENIER, LUSSIER & ASSOCIATES
BY:

Jean-Guy Routhier, F.e., M.e.s.

Encl. c.v.

TABLE OF CONTENTS

Page

INTRODUCTION

In 1980, the *Syndicat des Producteurs de Bois du Bas Saint-Laurent*, Cascades Paper, and Rexfor agreed to a research project aimed at analysing optimum methods of harvesting and transporting forest biomass produced during sanitation and silvicultural work in deciduous and mixed stands.

Through this project, the *Syndicat des Producteurs de Bois du Bas Saint-Laurent* hope to reduce the net cost of forest operations by selling recoverable forest biomass thereby alleviating the necessity of increasing budgets when harvesting larger areas of forest.

Cascades Paper Inc., Cabano Division, and the Rexfor Corporation saw the project as providing for an additional source of forest biomass for the production of pulp and energy at competitive cost and for improvement of regional forest potential, which is the very basis of their activity.

The Quebec Ministry of Energy and Resources, already deeply involved in the financing of forest works on privately owned land and seeing the interest displayed by forest owners and industrialists, joined in the project through the intermediary of the Quebec Office of Planning and Development (QOPD). The government stands to benefit greatly from the success of the project, because a fuller utilization of the forest biomass leads to an increased economic activity and contributes to the development of a previously overlooked natural resource.

The conception, development, and execution of this biomass recovery project was entrusted to the forestry consulting firm of Darveau, Grenier, Lussier and Associates, which, together with the *Groupement Forestier Agricole de Taché Inc.* and the *Corporation Agro-forestière du Témiscouata Inc.*, conducted the first phase of forest biomass recovery experiments in the autumn of 1981.

Following that work, Environment Canada, through the Canadian Forestry Service, was asked to take part in the project to analyse the data and to develop a simulation model whereby the implications of the different operating tactics could be analysed by computer and the most promising production tactics singled out for trial in the field. The Canadian Forestry Service, through the ENFOR program, agreed to share in the project provided that part of the biomass harvested would be earmarked for fuel which would be a substitute for oil and that forest biomass harvesting methods would be developed.

This report presents the simulation model designed to study biomass harvesting. It explains how the model is used and comments on the results produced. In addition, a sample simulation is presented to illustrate the model's applications. The model program, described in the appendix, uses APL computer language.

The simulation model comprises two modules. The first calculates the operating cost of a logging machine based on its purchase price, mechanical reliability, and productivity. The second is the actual simulation model, which simulates the activities and relationships of the machines involved in a biomass harvesting operation and calculates the relevant cost prices. In short, the first module estimates the operating costs of the machines, whereas the second simulates their respective operations.

CHAPTER 1
BIOMASS HARVESTING AND SIMULATION

1.1 Harvesting method

The experimental phase of autumn 1981 called on a tried and proven method of harvesting commercial stands. This method involves manual felling, skidding with conventional machines, chipping at the roadside, and delivery by trucks rigged with semi-trailers. This production system has not only demonstrated its efficiency for harvesting mature stands, it also offers the advantage of using equipment that for the most part is available locally.

The trial involved four types of skidders:

- a 90 HP articulated-frame wheeled skidder;
- a F-4 Dion tracked forwarder, used mostly at sloping sites;
- a 80 HP (John Deere 440) wheeled forwarder with a logging crane;
- a 125 HP (Volvo 861) wheeled clambunk skidder.

Chipping was handled by a 380 HP Morbark 22 chipper.

The semi-trailers measured 15 m long and accommodated average loads of 26.6 green tons.

The biomass was harvested from a variety of young mixed or deciduous stands where diameter at breast height (dbh) ranged from 2 to 15 cm. Clear or partial felling was done, and most of the trees felled were deciduous.

All of the biomass harvested was shipped to Cascades Paper's corrugated cardboard plant at Cabano where 90% of the supply was used to produce pulp and 10% to produce energy.

The trials conducted in the autumn of 1981 allowed us to evaluate the efficiency of selected machines in terms of the forest characteristics of the stands. Based on this knowledge, the equipment best suited for particular sites can be determined and minimum standards set to ensure the economic feasibility of biomass harvesting.

1.2 Biomass harvesting simulation

Computer simulation of a biomass harvesting operation makes it possible to analyse the productivity of a set of machines (skidders, chippers, and trucks) in various stands. In an activity such as roadside chipping, where the productivity of each phase of operation is greatly affected by the productivity of the preceding and following phases, simulation is the best technique for forecasting the overall productivity of a set of machines with acceptable accuracy. Adding up the rated productivities of the individual machines does not always yield satisfactory results.

The information gathered in the experimental phase of autumn 1981 is thus invaluable to establish the productivity parameters of the machines to be simulated. Through simulation this information can be used to evaluate biomass harvesting operations under conditions that were not encountered in the experimental phase or that call on a set of machines other than the one tested.

The simulation model constructed comprises two modules. The first module is a mathematical model for calculating the operating costs of the logging machines and trucks. This is a general-purpose module that can be used to establish the operating cost of any type of equipment. In this report it is called the "calculation module" and is described in Chapter 2.

The second module simulates the activity of the interdependent machines, that is, machines whose production is contingent on the preceding or following phase of operation. In the case of roadside chipping, for instance, the chipper operates only if there is a semi-trailer on hand since the machine projects the chips onto it. This part of the simulation model is called the "simulation module" in this report and is described in Chapter 3.

The simulation module provides for analysing chipping at the roadside by means of the three operating modes described below.

The first mode features a mobile chipper that advances along the woodpile. In this case skidding is an independant operation and is not simulated. This method of operation has certain disadvantages, such as:

- the need for an additional truck-tractor to move the chipper;
- a drop in productivity owing to the need to move the chipper and the semi-trailer several times in the course of loading;
- additional site preparation costs incurred to level and sometimes gravel a large area to allow for storage of the biomass and circulation of the chipper and the trucks.

In the other operating modes, the chipper is semi-stationary and is supplied by the skidders. Skidding, chipping, and trucking are thus interdependant. When skidding productivity is insufficient, the chipper must stop because of a shortage of biomass, whereas excessive skidder productivity or insufficient trucking halts skidding because of a lack of space to stack the wood near the chipper.

Where a semi-stationary chipper is used, the simulation module allows for simulation of the following two arrangements:

- the skidders are put on hold when there is no space to stack the biomass near the chipper;
- rather than halt skidding, the biomass is stacked in a storage pile not far from the chipper and later rehandled when the chipper can accommodate it.

It is problematical at first glance to determine which of these three operating modes is the most economical for specific operating conditions and a given set of machines. Computer simulation makes it possible to test the three modes at fairly low cost and evaluate the relative advantages of each. It also allows for evaluating how adding or removing one or more machines affects the operation.

CHAPTER 2

DESCRIPTION OF THE CALCULATION MODULE

The calculation module portion of the simulation model is stored in the CALCULCOUT workspace of the computer. The data are entered interactively by calling the CALCOUT function, which features three options:

1. DATA INPUT (LECTURE)
2. VERIFICATION (VÉRIFICATION)
3. EXECUTION (EXÉCUTION)

With the DATA INPUT option, the computer enters the data read-in mode and gives the instructions for entering the contents of the three forms described in section 2.1.

The VERIFICATION option controls the printing of the input data for checking purposes. Corrections are made by recalling DATA INPUT and correctly entering the erroneous inputs. The EXECUTION option controls execution of the calculations and printout of the results.

The three sections of this chapter describe and explain the following:

- the input data;
- the results;
- the calculations.

See Appendix 2 for a full description of the CALCULCOUT program.

2.1 Input data

Three forms are used to prepare the input data. It is advisable to fill in the forms before entering the data in the computer. Samples of the three forms are presented on pages 9, 12, and 16. They are:

- General Input Data (RENG)
- Basic Data for Each Logging Machine (ENGEX)
- Basic Data for Each Truck Type (CAM)

The sections below explain the information to be recorded on each form. Consulting the actual forms will make the explanation clearer.

2.1.1 General input data (RENG)

The items on this form are common to either all of the machines, e.g. interest rate, or most of them, e.g. operator hourly rate.

The values for items marked with an asterisk (*) may not be the same as indicated in the records of the individual machines. In this case, it is always the value indicated in the machine record that prevails, with the value on the RENG form used only when no value is specified in the machine record for a given item.

Investment Costs

The equipment depreciation cost may be established either by using a uniform annual cost, in which case a "1" is written on the first line of the form, or by spreading the cost to be depreciated over a number of annuities, as in leasing. In this case, a "1" is written on line 2 and the duration of the leasing period in years as well as the applicable interest rate are recorded on lines 3 and 4. If no depreciation is specified, i.e. a "0" is recorded on lines 1 and 2, the depreciation cost is disregarded in the calculations.

With either scheme only the difference between the equipment purchase cost and residual value, expressed as a percentage of the purchase price on line 5, is depreciated.

The interest rate applicable to the average investment is recorded on line 6. It is used to calculate the capital cost solely in the case of uniform depreciation. Where leasing is involved, the capital cost is incorporated in the annuity and does not appear as a separate item.

GENERAL INPUT DATA (RENG)

INVESTMENT COSTS		
Uniform annual depreciation (1 if applicable)	1	
Leasing (1 if applicable)	2	
* - Leasing period in years	3	
- Interest rate %	4	
*Residual value - % of purchase price	5	
Interest rate applicable to average investment	6	
SALARIES, FRINGE BENEFITS AND MISCELLANEOUS COSTS		
*Helpers hourly rate $	7	
*Operators hourly rate $	8	
Mechanics hourly rate $	9	
Fringe benefits % of hourly rates	10	
*Cost of parts for life of machine - % of purchase cost	11	
Mechanical Service hourly rate $	12	
Fuel cost - $ per unit of volume	13	
*Insurance cost per year - % of purchase price	14	
Hours of work per shift	15	
MISCELLANEOUS INPUTS		
Measurement unit (enter the appropriate code) 1 - cubic meter 2 - cunit 3 - cord 4 - board feet 5 - green ton 6 - oven dry ton	16	
Fuel unit of volume 1 - liter 2 - gallon	17	
Number of different logging machines	18	
Number of different trucks	19	

* These items may be specified differently for each machine on the following forms.

Salaries, Fringe Benefits, and Miscellaneous Costs

The hourly pay rates of helpers and operators are recorded on lines 7 and 8 respectively. If the fringe benefits are included in the salary or are to be disregarded, line 10 is left blank. Otherwise, the applicable fringe benefits are recorded as a percentage of the hourly rates on line 10.

The hourly pay rate for mechanics is recorded on line 9. This rate is not used in the calculations since the relevant cost is established in terms of the mechanical service hourly rate, which is recorded on line 12. It is used, however, as a reference for establishing the hourly cost of mechanical service, which must correspond to the average cost which the owner pays for repairs. That average cost may be substantially less than the rates charged by specialized garages, particularly if the owner himself handles a large part of the repair work.

Line 11 is used to estimate the cost of parts for the life of the machine. This cost is expressed as a percentage of the purchase price. It may differ in the individual machine records. For logging machines the cost of tires is included in the cost of parts, whereas it is calculated separately for trucks.

The fuel cost is recorded on line 13 in dollars per unit of volume (litre or gallon), which is specified on line 17.

On line 14 the annual cost of insurance is estimated as a percentage of the equipment purchase price. The insurance cost may be expressed differently, as an annual amount for instance, in the machine records.

The hours of work per shift recorded on line 15 must match the average duration of the normal workday. Given a 40-hour workweek for instance, 8 hours is recorded, even if the hours worked per day breaks down as 5 hours on Monday, 10 hours on Tuesday, Wednesday, and Thursday, and 5 hours on Friday, as is frequent in forest work.

Miscellaneous Inputs

The production measurement unit is entered on line 16; the codes are given and are explained on the form. As has been mentioned, line 17 indicates the fuel unit of volume.

Lines 18 and 19 are used to record respectively the number of logging machines and trucks for which operating costs are to be established. There is no limit on the number of logging machines or trucks that can be processed at the same time.

2.1.2 Basic data for each logging machine (ENGEX)

Data are recorded on this form for up to five machines. If more machines are involved, additional forms are used.

Values are recorded for items marked with an asterisk (*) only if they differ from those indicated for the same items on the preceding form (RENG).

Identification

A reference number, chosen by the user, is entered on line 1.

Line 2 calls for a function code. The current version allows for one of three codes:

- 1 for a skidder;
- 2 for a chipper;
- 3 for a truck.

Characteristics

Lines 3 through 6 indicate respectively purchase price, residual value as a percentage of the purchase price, leasing period where applicable and anticipated life of the logging machine in 1000 productive machine hours (PMH).

The scheduled machine hours per year for the type of machine involved are entered on line 7. For example, an operating period of 42

BASIC DATA FOR EACH LOGGING MACHINE (ENGEX)

	IDENTIFICATION					
1	Reference no.					
2	Function code					
	CHARACTERISTICS					
3	Purchase price 1000$					
*4	Residual value %					
*5	Leasing period					
6	Machine Life in 1000 PMH					
7	Scheduled machine hours per year					
8	Utilization rate %					
	ANNUAL EXPENSES					
*9	Insurance $/year					
10	Licence $/year					
11	Others $/year					
	CURENT EXPENSES					
12	Repair hours/ PMH					
	Parts costs:					
*13	- % of purchase price					
14	- $ per PMH					
15	- $ per year					
16	Lubricants $/PMH					
17	Others $/PMH					
18	Fuel consumption per PMH					
	LABOUR					
19	No of helpers					
*20	Helpers hourly rate					
21	No of operators					
*22	Operators hourly rate					
	PRODUCTIVITY					
23	Productivity per PMH					

* Fill-in only when value differs from the General Input Data form.

weeks at 40 hours per week gives 1680 hours. The machine hours logged by the same equipment in other operations during the same year are also to be considered. If, for instance, a farm tractor is used 200 hours per year for biomass harvesting and 900 hours for farm work, the total of the two activities, i.e. 1100 hours, is recorded.

The utilisation rate, or the ratio of productive machine hours to work hours, is recorded on line 8.

Annual Expenses

These are expenses which are incurred only once a year, generally change little from year to year, and are not contingent on the number of service hours of the machine. The annual insurance cost is recorded on line 9, the licence cost on line 10 and other expenses on line 11.

Other expenses can be used for the costs of machine storage during the off season, the stock of spare parts, special maintenance tools, accounting, etc.

Current Expenses

These are expenses which depend directly on the number of working hours of the logging machine.

The repair hours per PMH are recorded on line 12. The value for this item must reflect the average for the life of the machine. Thus, it is not limited to repair hours per week or month but encompasses annual mechanical overhaul and major repairs that occur several times in the life of a machine. The number of repair hours during the third or fourth year of service is generally a good benchmark. The mechanical service cost indicated on the RENG form is applied to this time, making it important that the hours counted match the time paid at the declared rate. It should be noted that the daily operator time spent on machine maintenance and minor repairs is not to be counted since it is already included in the operator's salary.

Lines 13 through 15 provide three ways of expressing the cost of parts, as a percentage of the purchase price, in dollars per PMH or in dollars per year. It is left to the user to choose the method most appropriate for him. If these lines are left blank, the parts costs will be calculated in terms of the machine purchase price based on the cost recorded on line 11 of the General Input Data form.

The cost of lubricants per PMH is entered on line 16. Other expenses accounted for in terms of PMH are entered on line 17.

Fuel consumption per PMH is recorded on line 18. This value is expressed in litres or gallons, depending on the measurement unit specified on the first form (RENG, line 17).

Labor

This section is used to specify the number of helpers and operators required to operate a given logging machine and to indicate their hourly pay rates. Given a felling and skidding team of two fellers, the latter can be assimilated to helpers in the calculation of the skidder operating cost so as to obtain the felling-skidding cost.

Productivity

Line 23 gives the mean productivity corresponding to the operating conditions for which the cost of a given logging machine is to be calculated. Productivity is expressed in PMH and recorded in the measurement unit indicated on line 16 of the General Input Data form.

2.1.3 Basic data for each truck type (CAM)

This form is used to record the data for four trucks of different types, one per column. If more than four trucks are involved, additional forms are used.

The first seventeen lines on this form are identical to those on the ENGEX form and are not explained again.

Current Expenses

Line 18 indicates the distance traveled per litre or gallon of fuel. The distance is given in kilometres if the metric system is used. Otherwise, it is expressed in miles.

Lines 19 through 21 are used to calculate the cost of tires. The number of tires on the truck and its trailer where applicable, is recorded on line 19. Line 20 gives the purchase cost of one tire and line 21 the average tire life in 1000 units of distance (km or mile).

The operator hourly pay rate is recorded on line 22.

Productivity

Unlike with logging machines, truck productivity is not recorded directly but is calculated on lines 23 through 26 from the input values.

Line 23 indicates the average truck load per run in the measurement unit entered on line 16 of the General Input Data form.

The trucking distance, or the distance from loading site to unloading site, is recorded on line 24.

Line 25 indicates average truck speed during the round trip, expressed in kilometres or miles per hour, depending on the unit of distance used.

The loading and unloading time per trucking cycle is entered in hours on line 26.

2.2 Calculation module results

The results produced by the calculation module are presented in a table headed Machine Operating Cost (see page 18). This table comprises the seven sections on page 17.

BASIC DATA FOR EACH TRUCK TYPE (CAM)

1	IDENTIFICATION Reference no.				
2	Function code				
3	CHARACTERISTICS Purchase price 1000$				
*4	Residual value %				
*5	Leasing period				
6	Machine Life in 1000 PMH				
7	Scheduled machine hours per year				
8	Utilization rate %				
*9	ANNUAL EXPENSES Insurance $/year				
10	Licence $/year				
11	Others $/year				
12	CURENT EXPENSES Repair hours/ PMH				
*13	Parts costs: - % of purchase price				
14	- $ per PMH				
15	- $ per year				
16	Lubricants $/PMH				
17	Others $/PMH				
18	Distance per fuel unit				
19	No of tires per truck				
20	Purchase price per tire				
21	Tire life in 1000 km. or miles				
*22	Operator hourly rate				
23	PRODUCTIVITY Truck load				
24	Trucking distance (one way)				
25	Average speed				
26	Loading and unloading time, hours				

* Fill-in only when value differs from the General Input Data form.

- Identification
- Annual Expenditures ($/day)
- Current Expenditures ($/PMH)
- Labor Expenditures
- Total Expenditures
- Productivity
- Cost per production unit (the green ton in the sample table on page 18).

As each item on the table is clearly identified, no further explanation is given.

2.3 Explanation of Calculations

This section explains some of the calculations performed to produce the Machine Operating Cost table. Items not subject to confusion are not explained.

Average Investment in $1000

This item is an estimate of the average capital invested over the life of the machine. In practice, the capital invested equals the purchase price at the time of acquisition and drops each year by the depreciation value to the residual value. The average investment is computed by the following formula, used in the forestry industry for many years:

$$\text{average investment} = \frac{[\text{purchase price} \times (\text{life} + 1)] + [\text{res. val.} \times (\text{life} - 1)]}{2 \times \text{life}}$$

Where: life = scheduled years of service of the machine.

Depreciation

The depreciation cost is expressed in dollars per day. The number of workdays per year is derived by dividing "scheduled machine hours per year" by "hours of work per shift". Where a machine is used both day and night, total workdays may exceed 365.

M A C H I N E   O P E R A T I N G   C O S T

	IDENTIFICATION			
REFERENCE NO	1	2	3	4
FUNCTION	SKID	SKID	CHIPP	TRUCK
SCHEDULED HOURS/YEAR	1800	1800	1800	2000
UTILIZATION RATE (o/o)	80	85	65	85
PURCHASE COST 1000$	60	40	250	80
AVERAGE INVEST. 1000$	42	28	171	56
	ANNUAL EXPENDITURES ($/DAY)			
DEPRECIATION	26.25	17.50	87.50	35.87
CAPITAL COST	31.22	20.81	128.44	37.67
INSURANCE AND OTHERS	14.00	11.00	47.50	29.15
TOTAL $/DAY	71.47	49.31	263.44	102.69
TOTAL $/PMH	9.93	6.45	45.03	13.42
	CURRENT EXPENDITURES ($/PMH)			
MECHANICAL SERVICE	2.25	1.80	2.25	2.25
PARTS	3.75	2.50	15.62	5.00
TIRES				3.59
FUEL	4.05	4.05	20.25	9.99
OTHERS	1.50	1.00	4.00	1.00
TOTAL $/PMH	11.55	9.35	42.12	21.83
	LABOUR EXPENDITURES			
$/DAY	98.82	98.82	186.66	98.82
$/PMH	13.72	12.92	31.91	12.92
	TOTAL EXPENDITURES			
$/DAY	253.45	219.66	696.53	368.48
$/PMH	35.20	28.71	119.06	48.17
	PRODUCTIVITY			
G T /DAY	50.40	38.25	140.40	77.62
G T /PMH	7.00	5.00	24.00	10.15
	COST PER GREEN TON			
ANNUAL EXPENSES	1.42	1.29	1.88	1.32
CURRENT EXPENSES	1.65	1.87	1.76	2.15
SUB-TOTAL	3.07	3.16	3.63	3.47
LABOUR	1.96	2.58	1.33	1.27
TOTAL	5.03	5.74	4.96	4.75

When depreciation of the machine cost is uniform, annual depreciation is calculated as follows:

$$\text{annual depreciation} = \frac{\text{purchase price} - \text{residual value}}{\text{life}}$$

Where the depreciation cost is likened to an annuity (leasing), annual depreciation is calculated as follows:

$$\text{annual depreciation} = (\text{purchase price} - \text{residual value}) \times \frac{i\,(1 + i)^n}{(1 + i)^n - 1}$$

Where: i = interest rate

n = duration of leasing plan in years

Capital Cost

This cost item represents the loss of profit on the average investment in the machine. Indeed, had the money used to purchase the machine been invested in stocks or other securities, it would have yielded interest. This loss of profit is thus to be considered in calculating the machine utilisation cost.

The capital cost is computed by applying the interest rate indicated on the General Input Data form to the "average investment" calculated above. However, this cost is calculated only for uniform depreciation of the value of the machine, for the annuity method of depreciation (leasing) takes the capital cost into account.

Mechanical Service

This item covers the cost of labor assigned to machine repair and is derived by multiplying "repair hours per PMH" by "mechanical service hourly rate".

Labor Expenditures

Labor expenditures per day or per PMH are calculated based on the helper and operator hourly rates, to which the fringe benefits are added.

Productivity

Truck productivity is expressed in production units (green tons, cubic metres, etc.) hauled from one place to another, per day or per PMH. It drops as the trucking distance increases.

The productivity value is obtained by dividing the load per run by the productive time required to make a run. The productive time is the sum of the times required for loading, unloading, and trucking at load and at no-load.

It should be pointed out that no adjustment is made to round out the number of runs per day to the nearest unit or to account for time lost late in the day when the last run is completed before the shift ends. These adjustments are made upon specification of the truck utilisation rate, which must reflect all such time losses, and are therefore not to be reconsidered when calculating productivity per day or per PMH. Furthermore, even if a truck makes a whole number of runs each day, the average number of runs after several days rarely comes out to a whole number.

2.4 Conclusions

As is shown by the Machine Operating Cost table, the calculation module is only a mathematical model for expressing the operating cost of a logging machine or truck in various forms. Taken together with the input forms, it is a clear and simple means of establishing the production costs of a given item of equipment.

The results produced by the calculation module provide for an initial comparison of similar machines. They also supply the values to be used for the annual expenditures and operating costs of the machines to be simulated.

The simulation module is used to estimate utilisation rates for the machines, taking their interrelated activities into account. If these rates differ from those used in the calculation module, they should be revised and the calculation module executed a second time.

CHAPTER 3
DESCRIPTION OF THE SIMULATION MODULE

This chapter explains the operation of the simulation module as well as the procedure for its use and the resulting tables. It also deals with the part that simulation can play in diagnosing the weak points of a particular operation and verifying how the proposed corrective measures will affect the overall harvesting system.

3.1 Characteristics of the simulation module

The simulation module developed for analysis of biomass chipping functions by events. When a given event occurs, the arrival of a truck at the chipping site for instance, the model examines the full effects of the event and generates the ensuing activities, given the current occupation of all the machines in the production system under review. The model then proceeds to the occurrence of the next event and generates the ensuing activities. This process is repeated until a full workday has been simulated. The following day is then simulated until the desired number of days are processed.

As an example event, let us consider the "arrival of skidder at chipper". The skidder's next activity depends on where the operator stacks its load as well as on the current activity at the chipping site. We will consider several possible activities at the site.

(1) The chipper is loading a truck.

(2) The chipper is waiting for wood to load a truck (there is a truck at the site).

(3) The chipper is temporarily down for one of the following reasons:
- the chipping knives are being changed or repaired;
- there is no truck at the chipping site;
- the shift is over.

In the first case (chipper in operation), the skidder will stack the wood next to the chipper and return to the forest for another load or else it will rehandle wood from the nearby storage pile, provided that the prescribed rehandling conditions prevail.

In the second (chipper waiting), the skidder will proceed as described above but in addition the chipper will resume working.

In the third (chipper temporarily down), the skidder will stack its load at the chipper if space allows. Otherwise, it will either wait or stack its load at a nearby storage pile and return to the forest.

As all of these situations and events are exclusive, simulation by means of a series of suitable trials identifies the appropriate action and generates the activities that derive from it. Note that each activity generated necessarily results in the occurrence of an event.

The events contained in the simulation module are listed below, with the routines that execute the required tests and generate the relevant activities identified in parentheses.

- Start-up of operation at beginning of day (DEBUT).
- Skidder arrival at chipper (DEBAR).
- Arrival of a skidder rehandling wood from storage pile (APPROCHE).
- Skidder breakdown termination (BRDEBAR).
- Termination of chipping of given biomass (DECHI).
- Termination of chipping knife change (CHGCOU).
- Chipper breakdown termination (BRDECHI).
- Truck arrival at chipping site (ARCAM).

The "REAL" sub-routine sequence controls the chronological occurrence of events and orders use of the appropriate sub-routine of events.

3.2 Utilization of Simulation Module

The simulation module is stored in the SIMULATION workspace of the computer. Data input and execution of the simulation are interactive. The process is triggered by the SIMULA function, which features the following options:

1. DATA INPUT (LECTURE)
2. VERIFICATION (VÉRIFICATION)
3. CORRECTION
4. START OF SIMULATION (DÉBUT)
5. END OF PROGRAM (FIN)

By responding with option 1, the user selects the DATA INPUT mode and the computer successively issues instructions for entering the data, one form at a time.

The VERIFICATION option initiates printout of the storage data for comparison against the forms. Where required, the correction procedure is initiated by the CORRECTION option. Execution of the simulation (SIMULA) is triggered by "DEBUT" and terminated by "FIN".

Forms have been written up to prepare the data in advance and facilitate their error-free entry in the computer. The next section of this chapter itemizes the contents of these forms. The data requirements can be classed in four series:

- a descriptive data series that identifies the operating mode of the simulated equipment and the machine types and describes the stand and logging site where the simulation takes place;
- a data series that indicates the specific characteristics of the simulation, e.g. number of days simulated, workday duration and amount of biomass that can be stored near the chipper;
- a data series on the operating characteristics of each machine, e.g. number of breakdowns, load capacity and operating costs;
- a data series that specifies the time duration of each activity, which can be indicated by a value representing mean duration or

determined at random from a given set of data in line with precise rules of probability. In the first instance, the duration of the activity will remain the same throughout the simulation, whereas in the second, the execution time will be different for each occurrence of the activity.

Following the computer instructions, the simulation starts and it terminates once all days to be simulated have been processed. Four types of reports, or printouts, can be produced.

- The activity trace tracks the activity of each machine during the simulated day. This printout is used to check the proper execution of the simulation and to observe the operation as it would actually occur in the forest. As a rule, this report need be produced for only one day of simulation.
- The machine occupation printout breaks down the workday of each machine into productive and unproductive elements and indicates its utilisation and availability rates. It also gives production by type of activity as well as total cost for the day. This report is produced for selected simulated days and for all simulated days.
- The cost breakdown report distributes costs among labor, ownership expenses (fixed) and machine operating expenses. It also gives a cost breakdown by unit produced and type of activity. As with the preceding report, it is produced for selected simulated days and for all days simulated.
- The final report presents productivity statistics, indicating the number of observations, mean value, standard deviation, and minimum and maximum values for selected variables. This report is produced once for each simulation.

Section 3.4 itemizes and gives examples of each of these reports.

Taken as a whole, these computer printouts provide for diagnosis of the simulated operation. For instance, the machine occupation table may reveal that the chipper is actually chipping only 42% of the time, whereas it spends 34% of its time waiting for a truck. In this case, it would be advisable to consider adding another truck and repeating the simulation. This would certainly shorten the chipper's waiting time but would probably prolong that of the trucks, in addition to which there might no longer be enough skidders for the job. Analysis of the new machine occupation and cost breakdown tables will show the impact of adding another truck, further indicating whether or not a higher chipper occupation rate entails a drop in costs. In light of this new analysis, it will no doubt be advisable to make further changes in the number of test machines and repeat the simulation once again.

Through a series of simulations and consideration of the effect of the changes tested, simulation analysis will point out the most favorable operating mode or modes regarding productivity or cost price.

3.3 Description of input forms

The four simulation input forms are:

- Description of chipping operation and logging conditions
- Characteristics of the simulation
- Data for each machine
- Time duration of activities in minutes

A sample of each form is presented on pages 27, 29, 32, and 37. This section describes and explains the information to be recorded on the forms and the procedure for entering it in the computer.

Description of Chipping Operation and Logging Conditions

The data items on this form are entered in the computer by specifying the appropriate code in response to the first prompt issued by the DATA INPUT function, i.e. code 1.

The computer then issues a prompt for each item to be entered, in the same order as the items appear on the form. Following is a description of the different items.

The first item is the identification of the project scheduled for simulation. Next is the ID of the simulation, indicated by a number or a brief description of the elements to be simulated (30 characters). The date is the final item in this first set of information.

The next item involves the operating mode of the simulation, which is indicated by one of the codes explained on the form. Code 1 designates chipping from woodpiles at the roadside, in which case skidding is a separate operation and is not simulated. Furthermore, no skidder will appear on the machine table.

Code 2 denotes that the skidders are put on hold when the woodpile is full at the chipper. In this situation as in the one described below, the model simulates skidding, chipping, and trucking.

Code 3 is used when the skidders pile wood near the chipping site if they cannot unload directly at the chipper. This operating mode requires subsequent rehandling to move the wood to the stationary chipper. Rehandling occurs when the woodpile at the chipper drops below a certain level, which is specified on the next form. No more than one skidder is ever assigned to rehandling.

The next set of items concerns the number and description of the different types of machines. As a rule, skidder types are differentiated on the basis of productivity, operating cost, or load capacity. However, describing two identical types as being different does not produce an error. The result is simply that the Time Duration of Activities table describes the duration for each type specified, thus repeating the same data twice since the machines are identical.

In the next set of items the number of truck types is specified and each type is described. This is followed by a description of the chipper.

PROJECT:____________________ SIMULATION__________ DATE:__________

DESCRIPTION OF CHIPPING OPERATION AND LOGGING CONDITIONS.

OPERATING MODE OF SIMULATION (enter appropriate code): ________

1- Chipping from wood piles at roadside (mobile chipper).

2- Stationary chipper without a storage pile close to chipper; skidders waiting when chipper pile is full.

3- Stationary chipper with a storage pile close to chipper; no skidders waiting.

NUMBER OF SKIDDER TYPES: ________

Description of skidder type 1: ____________________

Description of skidder type 2: ____________________

Description of skidder type 3: ____________________

NUMBER OF TRUCK TYPES: ________

Description of truck type 1: ____________________

Description of truck type 2: ____________________

Description of truck type 3: ____________________

DESCRIPTION OF CHIPPER: ____________________

DESCRIPTION OF STAND AND LOGGING SITE:

Stand: ____________________

Cutting technique ____________________

Trees harvested per hectare: ____________________

Volume logged per hectare: ____________________

Terrain characteristics: - slope in % ____________________

- ground bearing capacity ____________________
- ground moisture ____________________

Trucking distance: ________ ____________________ km

The last section of the form is used to describe the stand and the logging site corresponding to the productivities used in the simulation. This information is provided solely for purposes of description and has no bearing on execution of the simulation.

Characteristics of the Simulation

This form is used to record values for a series of variables required for the simulation. For each item the name of the corresponding variable in the simulation program is indicated in parentheses. In case of error, one simply enters the variable correctly. For instance, to change the number of days of simulation from 3 to 5, one enters

NJAS ← 5

The number of days to be simulated is written on line 1. It is preferable to simulate only a few days during the first tryout of the program. This may be sufficient to detect any major problems and substantiate certain changes before undertaking more simulations.

Line 2 indicates the days for which daily reports are desired. The daily report comprises two printouts, one titled Occupation of Machines and the other Breakdown of Costs. There is no restriction on the number of days that can be specified here and the days may be consecutive or non-consecutive. The user is advised to request a daily report for at least the first day.

The days for activity trace are indicated on line 3. The trace tracks movement of all the machines during the day and has two roles: (1) it is used upon development of the simulation model to ensure that the simulation logic is realistic; (2) it provides an opportunity to visualize every aspect of an operation. A trace should be requested whenever the daily results are surprising.

In sum, these first three items define the duration of the simulation and specify the reports that are produced.

CHARACTERISTICS OF THE SIMULATION

Days of simulation (NJAS): ________

Presentation of daily report for days (IMPRQ): ________

Trace of activities presented for days (TRAJR): ________

Biomass measurement unit (enter appropriate code): ________

1- Cubic meter	2- Cunits	3- Cord
4- Board feet	5- Green ton	6- Oven dry ton

Maximum amount of wood that could be stored at chipper (BIOMAX): ________

Wood is rehandled from storage piles when amount of wood at chipper is less than (BIOAP): ________

Amount of wood stored close to chipper site at beginning of simulation (BIOD): ________

Amount of wood stored at chipper at beginning of simulation (BIOR): ________

Truck loads chipped with same set of knives (INTCOUN): ________

Working minutes per shift (JOUR): ________

Overtime premium as a % of the regular rate (PRIME): ________

Fringe benefits, as a % of salaries (BENMARG): ________

The next item calls for a code indicating the biomass measurement unit, i.e. the unit used to measure the load capacity and productivity of the machines. The form enumerates the six possible codes. The remaining items specify the variables that must be quantified for simulation purposes.

- Maximum amount of wood that can be stored at the chipper (BIOMAX). Given a mobile chipper working from a roadside woodpile (code 1 operating mode), this variable is irrelevant and the data input procedure skips it.
- The amount of wood at the chipper is below a certain level (BIOAP) and a skidder is assigned to rehandle wood from the nearby storage pile (operating mode 3). This item is skipped upon selection of modes 1 or 2, which do not provide for rehandling. The skidder assigned to rehandling continues this activity as long as chipping is under way or the amount of wood at the chipper is below the maximum amount (BIOMAX), providing that there is a storage pile to be rehandled.
- The amount of wood stacked at the chipper at the beginning of the simulation (BIOD). This variable indicates the situation at the start of simulation. If the chipper works from a roadside woodpile (mode 1), the program specifies this variable (BIOD) as 100 000 and the corresponding prompt does not appear at the time of data input.
- The number of truckloads that can be chipped with the same set of knives (INTCOUN).
- The working minutes per shift (JOUR). This variable is used to compute overtime and to terminate the shift under certain circumstances.
- Overtime premium expressed as a percentage of the regular rate (PRIME). For example, if overtime is paid at time-and-a-half, the premium is 50%. It should be noted that the fringe benefits are not added to the overtime labor cost.
- The final item specifies the fringe benefit cost as a percentage of the base rate (BENMARG). If the fringe benefits are included

in the specified salary or are to be disregarded, a "0" is written on this line.

Data for Each Machine

Unlike the first two forms, this one is designed as a table on which each line corresponds to a different machine. All of the machines involved in the simulation are recorded on this table. However, the user should bear in mind that if the chipper works from a woodpile, skidding is not simulated and no skidder is included in this table. The skidding cost is derived by the calculation module.

The following paragraphs describe the information to be entered in each column.

The first two columns, headed MACHINE, are used to specify the machine's function code and type. The function codes are the same as for the calculation module:

1. for skidder;
2. for chipper;
3. for truck.

The type is identified by means of a number scheme starting with "1" for each machine type. The numbers match the type descriptions given on the Description of Chipping Operation and Logging Conditions form.

The next column is headed STARTING TIME. This denotes not the actual time but the number of minutes between the start of each machine's shift. If all of the machines started working at the same time, 0 or any value under 4000 could be entered on all the lines in this column. In actual practice, each truck in the operation begins its shift at a different time, with the first truck generally starting 30 to 60 minutes before the chipper and the skidders so as to have time to reach the chipping site. The starting time for the first machine is generally assigned the value 0, with the times for the other machines indicated accordingly. Negative values are not used for this item.

DATA FOR EACH MACHINE (ENTRE)

	MACHINE		STARTING	NO BREAK-	LOAD	**	MACHINE COSTS				OPERATOR'S
	FUNCTION	TYPE	TIME	DOWM PER 1000CYCLES	PER CYCLE		OWNERSHIP COSTS	OPERATING COSTS			SALARY
								ACT.A	ACT.B	ACT.C	
			(min)				($/DAY)	($/PMH)	($/PMH)	($/PMH)	($/H)
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											

** Skidders: enter 1 when unit type can rehandle wood at chipper site.
Chipper: not applicable.
Trucks: minimum time (minutes) required at the end of a shift to produce one more load.

Function code: 1- Skidder 2- Chipper 3- Truck

	ACTIVITY A	ACTIVITY B	ACTIVITY C
Skidder	Skidding from stump to chipper	Skidding from stump to a storage pile close to chipper	Rehandling from storage pile to chipper
Chipper	Chipping	Changing knives	Not applicable
Truck	Loading	Trucking and unloading	Not applicable

The column headed NO. BREAKDOWNS PER 1000 CYCLES is used to generate random breakdowns during the simulation. The breakdowns are generated in line with the probability recorded in this column. If, for instance, 50 is specified for a truck, the probability of a truck breakdown during each run (one duty cycle) is 0.05 (50/1000) and after simulation of 1000 runs, there should have been an average of 50 breakdowns.

Very few reference tables exist to aid the user in selecting a value for this column. Experience with the type of machine being simulated is the best guide. Should the user notice after a few tests that the number of breakdowns generated is too unrealistic, he will have to revise this value up or down, depending on whether the number specified is too low or too high.

It is important to remember that the number of breakdowns is given per 1000 duty cycles and that the duration of a cycle varies with each machine. The shorter the cycle, the fewer breakdowns are expected. A chipper's duty cycle corresponds to the loading of a truck.

The LOAD PER CYCLE column indicates the load capacity of each machine in the measurement unit, e.g. cubic metre or green ton, specified on the Characteristics of the Simulation form. As the chipper is not a transport vehicle and carries no load, 0 is entered in this column.

The column marked ** applies differently for different machines, as is indicated on the form. For skidders it identifies the machines that can be assigned to rehandle wood stored at the chipping site. The value 1 is recorded for the machines to which this applies and 0 for the others. This column is not applicable for the chipper. Still, a value must be specified at the time of data input.

For trucks the ** column indicates the minimum time required at the end of a shift to produce one more load. This time is measured in terms of the end of the chipper's shift, not that of the trucks. Given a loaded truck, if the chipper's remaining work time is less than the value indicated, the truck will deliver its load but will not return to the chipping site. The time is specified in minutes and may differ for each truck. Thus, the times recorded in this column terminate the shift of the trucks, which in turn results in stoppage of the skidders and the chipper.

For example, if a trucking cycle (loading, delivery, unloading, and return) takes 3 hours (180 minutes), it may be decided that no truck leaving the chipping site will return when only two and a half hours (150 minutes) remain in the shift. In this case, the value 150 is entered in the column.

The next group of columns are used to specify the machine costs, which fall into two classes:

- ownership costs;
- operating costs.

Ownership costs are often referred to as fixed costs and encompass the annual expenditures incurred regardless of the hours of operation of the machine. These are costs that every owner must assume, whence the term "ownership costs." They cover depreciation, capital cost, insurance, licence fees, and any other annual outlay and are expressed in dollars per day.

Operating costs are all those incurred while a machine is in use. The main items here are mechanical service and parts costs, which cover normal wear, tires, and fuel. Operating costs are expressed in dollars per PMH. The form makes it possible to vary these costs in terms of different machine activities.

The productive time of the skidders can be divided among three different activities.

- Activity A: Skidding from the stump to the chipper.
- Activity B: Skidding from the stump to a storage pile close to the chipper.
- Activity C: Rehandling wood from the storage pile to the chipper.

There are two possible activities for the chipper.

- Activity A: Chipping.
- Activity B: Changing knives. Given that this activity is vital to operation, we have chosen to include it in productive time rather than mechanical delays.

Truck productive time is also divided into two activities.

- Activity A: Loading.
- Activity B: Trucking, unloading, and return to the chipping site.

Activity C is not applicable for the chipper or the trucks.

The last column on this table is used to indicate the hourly pay rate of the operator of each machine. Where there is more than one operator per machine, the total hourly rates of all the operators or helpers is recorded here. To calculate the costs, the program increases the value specified in this column by the percentage of fringe benefits recorded on the Characteristics of the Simulation form.

Time Duration of Activities in Minutes

This form, like the preceding one, is designed as a table. It is used to specify the duration of activities for each machine type. The number of entries depends on the number of machine types and different activities for each machine. Machines of the same type all have the same duration of activities.

The data from this table are entered in the computer line by line. Following is an explanation of the information to record in each column.

The first two columns specify machine function and type, using the same codes as for the Data for Each Machine (ENTRE) form.

The next two columns identify the activity by a code and a description. Only the code is entered in the computer; the description is provided for reference purposes. There are five activity codes, each of which is specific to a particular machine type, except for codes 4 and 5, which are common to all types. The table headed Time Duration of Activities - Definition of Codes (page 38) defines the codes for each machine. The user is advised to consult this table when completing the form.

Next is the PROBABILITY DISTRIBUTION column, followed by four PARAMETER columns. These spaces are used to specify the probability distribution applicable to the duration of the activity and the parameters that typify the distribution. The Time Duration of Activities - Definition of Codes table gives the codes for each probability distribution and defines the parameters.

For example, the skidding cycle of a type 2 skidder will be described as follows.

- Enter "1" in the FUNCTION column to indicate the skidder code.
- Enter "2" in the TYPE column to indicate a type 2 machine.
- Enter "1" in the ACTIVITY-CODE group to indicate a skidding cycle.
- Enter "2" in the PROBABILITY DISTRIBUTION column to indicate that the duration of the skidding cycle varies according to normal distribution. If another probability distribution is more appropriate, enter the corresponding code.

- Since normal distribution has been selected for this example, each of the four parameters is assigned a value as follows:
  - mean skidding cycle duration under parameter 1;
  - standard deviation of skidding cycle duration under parameter 2;
  - minimum skidding cycle duration in minutes under parameter 3;
  - maximum skidding cycle duration under parameter 4.

It should be noted that the duration of each activity is expressed in minutes. In the case of chipping (chipper activity code 1), the time

TIME DURATION OF ACTIVITIES IN MINUTES (DURACT).

	MACHINE		ACTIVITY		PROBABILITY	PARAMETERS			
	FCT.	TYPE	CODE	DESCRIPTION	DISTRIBUTION	1	2	3	4
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									

TIME DURATION OF ACTIVITIES
DEFINITION OF CODES

ACTIVITIES CODES.

MACHINE	CODE	ACTIVITY DESCRIPTION
Skidder	1	Skidding cycle
	2	Rehandling cycle (rehandling of wood stored close to chipper)
	3	Not used
Chipper	1	Chipping (chipping time per unit of volume or mass)
	2	Changing knives
	3	Not used
Truck	1	Delivery and return trip to chipping site
	2	Delivery to the mill with no return to chipping site
	3	Empty trip to chipping site (first trip of the day)
All machines	4	Breakdown
	5	Maintenance and start-up at beginning of shift

PROBABILITY DISTRIBUTIONS CODES

PROB. DISTRIBUTION		PARAMETERS			
DESCRIPTION	CODE	1	2	3	4
Average*	1	Mean	-	-	-
Normal	2	Mean	Standard deviation	Minimum	Maximum
Uniform	3	Minimum	Maximum	-	-
Exponential	4	Mean	Minimum	Maximum	-

* Duration of activity is the mean time for all occurences.

required to chip one biomass unit, e.g. cubic metre or green ton, is indicated.

When normal or exponential probability distribution is used, if the random value is less than the specified minimum or more than the specified maximum, the program takes the minimum or maximum value as applicable, instead of the random value.

3.4 Presentation of simulation results

This section covers the following tables:

- Occupation of Machines in Hours;
- Breakdown of Costs;
- Statistics on Productivity.

The trace and its use are explained in section 3.5.

Occupation of Machines in Hours

A sample of this table is presented on page 41. When this table gives the result for one day of simulation, TABLE FOR DAY X is written under the heading. When it gives the results for all of the days simulated, AVERAGE VALUES PER DAY FOR Y DAYS appears. As the table heading indicates, all times are expressed in hours.

The first three columns identify each machine as follows:

REF: machine reference number;
FCT: machine function code;
TYP: machine type code.

The next three columns break down PRODUCTIVE TIME by type of activity. Refer to pages 34 and 35 for the definition of activities A, B, and C.

The waiting times that occur during the day are entered in the next two columns. There are two waiting causes (CSE 1 and CSE 2) for each machine. They are explained at the bottom of the table.

The next columns indicate the operating delay times:

MECA: refers to all mechanical delays, i.e. the time of machine maintenance and start-up at the beginning of the shift, as well as the duration of breakdowns;

OTHER: insofar as simulation is concerned, this denotes an operational delay, i.e. time lost when a machine completes its shift ahead of schedule. If, for instance, the chipper finishes loading the last truck and 45 minutes remain in the shift, there will be a delay of 0.75 hour.

The hours worked for MACH (machines) and MEN follow. The machine time is expressed to the hundredth and is the sum of all the times recorded in the preceding columns. The man-hour time is rounded to the next half-hour. For example, if the hours worked come to 9.18, the value 9.5 is recorded. For, it is standard practice in the forestry industry to measure overtime in half-hours.

The UTILISATION column gives the machine utilisation rate, or the ratio of productive time to total time worked.

The AVAILABILITY column shows the availability rate, or the proportion of hours worked during which the machine is mechanically fit to work.

The next columns headed PRODUCTION indicate daily production by activity. For the chipper the number of knife changes during the day is recorded under activity B.

The last column is headed COSTS and shows the daily costs incurred for each machine. This covers the costs of labor, ownership, and operation.

This table groups the machines by function. We thus have the skidders, the chipper, and the trucks. For each group of machines the

PROJECT: CABANO SIMULATION: 1 (1 FORWARDER, 2 SKIDDERS, 2 TRUCKS) DATE: 25/05/82

OCCUPATION OF MACHINES IN HOURS

TABLE FOR DAY 1

MACHINE	PRODUCTIVE TIME			WAITING		DELAYS		HOURS WORKED		UTILI-	AVAILA	PRODUCTION			
REF FCT TYP	ACT. A	ACT. B	ACT. C	CSE 1	CSE 2	MECA.	OTHER	MACH.	MEN	SATION	BILITY	ACT. A	ACT. B	ACT. C	COSTS
												(G T)	(G T)	(G T)	($)
SKIDDER															
1 1 1	8.57					0.69		9.26	9.5	93	93	60			287.28
2 1 2	6.40	0.34	0.91			1.36		9.00	9.0	85	85	29	2	11	225.79
3 1 2	6.57	0.31	1.66			0.45		9.00	9.0	95	95	32	2	18	235.00
AVERAGE	7.18	0.22	0.86			0.83		9.09	9.2			40	1	10	249.36
PERCENTAGE	79	2	9			9		100		91	91				
CHIPPER															
4 2 1	5.57	0.50		0.06	1.79	0.42	0.65	9.00	9.0	67	95	140	1		737.17
PERCENTAGE	62	6		1	20	5	7	100		67	95				
TRUCK															
5 3 1	3.42	5.57		0.61	0.06	0.47		10.13	10.5	89	95	84	84		419.98
6 3 1	2.15	4.68				0.48	1.70	9.00	9.0	76	95	56	56		351.94
AVERAGE	2.79	5.12		0.30	0.03	0.47	0.85	9.57	9.8			70	70		385.96
PERCENTAGE	29	54		3		5	9	100		83	95				

	WAITING CAUSE 1	WAITING CAUSE 2
SKIDDER	SURPLUS OF WOOD AT CHIPPER	DOES NOT APPLY
CHIPPER	SHORTAGE OF WOOD	NO TRUCK
TRUCK	CHIPPER IS BUSY	SHORTAGE OF WOOD

AVERAGE line gives the average value of each column; the PERCENTAGE line gives the percentage distribution of time worked.

Assessment of the co-ordination of the operation being simulated is based on this Occupation of Machines in Hours table, which is used to ascertain whether excessive time is lost through waiting or whether the skidders spend too much time on activities B and C (temporary skidding and rehandling) or to pinpoint any other weaknesses in the production system under review.

Breakdown of Costs

A sample of the Breakdown of Costs table is provided on page 43. As its name indicates, this table presents the cost distribution by machine, group of machines and activity. It complements the preceding table and provides for evaluation of the production cost.

The first three columns are used to identify the machines and are the same as those on the preceding table.

The next four columns break down daily expenses as follows:

- labor costs;
- machine costs, broken down into
  - ownership costs (OWNER);
  - operating costs (OPER.);
  - total labor and machine costs.

The next columns indicate costs per green ton (the measurement unit in our example) for each type of activity. These costs are broken down among the items of labor (LAB) and machine (MACH) and the total is given.

The final three columns are headed COST PER GREEN TON CHIPPED. These costs are presented by group of machines of the same function, not by individual machines. We therefore have in succession the cost of skidding, chipping, and trucking per green ton chipped. The grand total gives the production cost for all of the machines simulated.

PROJECT: CABANO SIMULATION: 1 (1 FORWARDER, 2 SKIDDERS, 2 TRUCKS) DATE: 25/05/82

BREAKDOWN OF COSTS

AVERAGE VALUES PER DAY FOR 3 DAYS

MACHINE			EXPENSES PER DAY				COST PER GREEN TON									COST PER GREEN TON CHIPPED		
				MACHINE		TOTAL	ACTIVITY A			ACTIVITY B			ACTIVITY C					
REF	FCT	TYP	LABOUR	OWNER	OPER.		LAB.	MACH.	TOTAL	LAB.	MACH.	TOTAL	LAB.	MACH.	TOTAL	LAB.	MACH.	TOTAL
SKIDDER																		
1	1	1	112	72	115	299	1.82	3.02	4.85	1.77	2.93	4.70						
2	1	2	108	49	80	237	2.81	3.37	6.18	2.67	3.20	5.87	1.29	1.55	2.84			
3	1	2	108	49	82	239	2.79	3.38	6.16	2.83	3.44	6.27	1.24	1.51	2.75			
SUB-TOTAL:			328	170	277	775										2.34	3.19	5.53
AVERAGE:							2.34	3.21	5.55	2.27	3.12	5.39	1.28	1.54	2.81			
CHIPPER																		
4	2	1	195	263	298	756	1.28	3.69	4.97	15.52	44.58	60.10				1.39	4.01	5.40
TRUCK																		
5	3	1	130	103	211	444	0.56	1.36	1.92	0.99	2.38	3.37						
6	3	1	99	103	148	350	0.60	1.54	2.14	1.16	2.95	4.11						
SUB-TOTAL:			229	206	359	794										1.64	4.04	5.67
AVERAGE:							0.58	1.43	2.01	1.06	2.61	3.67						
TOTAL			752	639	934	2325										5.37	11.23	16.61

Statistics on Productivity

This table, a sample of which is provided on page 45, takes an approach entirely different from that of the two tables just described by providing information on specific variables rather than on machines. It aids in understanding the simulated operation and enhances on its characterization. This table is produced for each simulation to provide statistics on the six variables below.

- Truck waiting time attributable to the chipper.
- Chipper waiting time when no truck is available.
- Chipper waiting time attributable to skidding (shortage of wood). It should be noted that the truck waiting time attributable to skidding is the same as that of the chipper since a shortage of wood holds up both chipper and truck.
- Skidders' waiting time.
- Amount of biomass chipped per day.
- Daily cost per unit chipped.

The statistics listed below are given for each of these variables.

- Number of observations (NO OBS), or the number of times the variable occurred, e.g. how many times a truck waited for the chipper.
- Mean value observed (MEAN) (note that all waiting times are expressed in minutes).
- Standard deviation (STD. DEV.) of the observation data.
- MINIMUM value.
- MAXIMUM value.

For example, if this table allocates the "trucks waiting for chipper" variable a mean value of 19 minutes, a standard deviation of 22 minutes, and a maximum value of 63 minutes, it is very likely that the truck start-ups are not properly staggered at the beginning of the shift. Indeed, if the second truck begins its shift 30 minutes after the first whereas it takes 80 to 90 minutes to load the first truck, the second truck will wait 50 to 60 minutes at the start of its shift for the chipper to load the first truck. Such situations can be checked by means of the trace.

PROJECT: CABANO   SIMULATION: 1 (1 FORWARDER, 2 SKIDDERS, 2 TRUCKS)   DATE: 27/05/82

STATISTICS ON PRODUCTIVITY

NUMBER OF DAYS SIMULATED: 3

VARIABLES	NO OBS	MEAN	STD.DEV.	MINIMUM	MAXIMUM
TRUCKS WAITING FOR CHIPPER	3	37.40	28.93	8.93	66.76
CHIPPER WAITING FOR TRUCK	12	24.86	23.98	5.21	89.81
CHIPPER WAITING FOR SKIDDER	25	5.17	3.98	0.08	13.81
SKIDDERS WAITING TIME					
BIOMASS CHIPPED PER DAY IN GREEN TONS	3	140.00		140.00	140.00
DAILY COST PER UNIT CHIPPED	3	16.61	0.46	16.12	17.04

If simulation of two different operating modes produces comparable costs per unit chippped, \$26.15 and \$26.40 per green ton for instance, but very different standard deviations, \$1.70 and \$0.75, the system with the lower standard deviation is preferable since although the mean cost is slightly higher in our example (by \$0.25 per green ton), the risks appear to be smaller, as corroborated by the lower standard deviation.

These examples illustrate the uses for the Statistics on Productivity table.

3.5 Explanation and use of activity trace

The trace is used to track machine activity during simulation. The sample trace on page 48 covers simulation of a mobile chipper working from a woodpile (operating mode 1). Therefore no skidder is involved.

For each event the trace presents:

- time of occurrence of the event, calculated in minutes from a given base time;
- identification of the activity just completed;
- identification of the machines affected by the event and of the ensuing activities, along with their occurrence times.

The activity just completed or the event having just occurred is identified by the name of the corresponding routine.

DEBAR: Arrival of a skidder at the chipper.

CDEBAR: Continuation of skidding. This routine generates the first skidding cycle of each machine at the start of the shift.

APPROCHE: Arrival of a skidder with a load from the storage pile (rehandling) instead of the felling site.

BRDEBAR: Skidder breakdown termination.

DECHI: Termination of chipping of given biomass.

CHGCOU: Termination of chipping knife change. This routine also starts up the chipper at the beginning of the shift.

BRDECHI: Chipper breakdown termination.

ARCAM: Arrival of a truck at the chipping site.

Each machine affected by the event having just occurred is identified by five entries on a single line. The trace thus features as many lines as there are machines. The information below is given for each machine.

-Machine ID, i.e. skidder, chipper, or truck.

-Machine reference number.

-Machine type.

-Code of next event:

1 = DEBAR

2 = APPROCHE

3 = BRDEBAR

4 = DECHI

5 = CHGCOU

6 = BRDECHI

7 = ARCAM

8 = CDEBAR

9 = a skidder on hold

10 = chipper and truck on hold because of shortage of wood

11 = chipper waiting for truck

12 = truck waiting for chipper

-time (HR) of occurrence of the next event; however, when a machine is put on hold, instead of the occurrence time of the next event, the time at which waiting began is entered as a negative value.

When the next event is the end of the workday, the trace indicates not the code of the next event but the time at which the shift ended and the value 6000 is indicated for HR. When the HR column shows 6000 for all the machines, the REAL routine recognizes that the day's simulation is completed.

```
                    TRACE FOR DAY 1

TIME: 72.16
   ACTIVITY: CHGCOU
  _CHIPPER          1   1     11 HRE ¯72.16
TIME: 73.36
   ACTIVITY: ARCAM
   CHIPPER          1   1      4 HRE 135.98
   TRUCK            2   1      4 HRE 135.98
TIME: 135.9820051
  ACTIVITY: DECHI
  TRUCK             2   1      7 HRE 255.74
  CHIPPER           1   1      5 HRE 165.98
TIME: 143.59
   ACTIVITY: ARCAM
   TRUCK            3   1     12 HRE¯143.59
TIME: 165.9820051
  ACTIVITY: CHGCOU
  CHIPPER           1   1      4 HRE 210.78
  TRUCK             3   1      4 HRE 210.78
TIME: 210.7820051
  ACTIVITY: DECHI
  CHIPPER           3   1      7 HRE 327.28
  TRUCK             1   1     11 HRE¯210.78
TIME: 255.7420051
  ACTIVITY: ARCAM
  CHIPPER           1   1      4 HRE 306.32
  TRUCK             2   1      4 HRE 306.32
TIME: 306.3194879
  ACTIVITY: DECHI
  TRUCK             2   1      7 HRE 418.75
  CHIPPER           1   1     11 HRE¯306.32
TIME: 327.2820051
  ACTIVITY: ARCAM
  CHIPPER           1   1      4 HRE 390.44
  TRUCK             3   1      4 HRE 390.44
TIME: 390.4411591
  ACTIVITY: DECHI
  TRUCK             3   1      7 HRE 509.14
  CHIPPER           1   1     11 HRE¯390.44
TIME: 418.7494879
  ACTIVITY: ARCAM
  CHIPPER           1   1      4 HRE 463.55
  TRUCK             2   1      4 HRE 463.55
TIME: 463.5494879
  ACTIVITY: DECHI
  TRUCK             2   1    541 HRE6000.00
  CHIPPER           1   1      5 HRE 493.55
TIME: 493.5494879
  ACTIVITY: CHGCOU
  CHIPPER           1   1     11 HRE¯493.55
TIME: 509.1411591
  ACTIVITY: ARCAM
  CHIPPER           1   1      4 HRE 584.14
  TRUCK             3   1      4 HRE 584.14
TIME: 584.1357993
  ACTIVITY: DECHI
  TRUCK             3   1    647 HRE6000.00
  CHIPPER           1   1    584 HRE6000.00
```

We will now track the activities occurring during the day traced on page 48.

In this simulation the chipper begins its shift at time 45, truck 2 at time 0, and truck 3 at time 90. The duration of the shift is 540 minutes (9 hours).

The first event shown on the trace occurs at 72.16 and is coded CHGCOU, which denotes here the start of the chipper's shift, not a change of knives. Chipper maintenance and start-up took 27.16 minutes (72.1 - 45.00), or the difference between the time the chipper is ready for work (72.16) and the time the shift begins (45.00). As there is no truck at the site, the chipper is put on hold for a truck (code 11) at 72.16.

The next event, at 73.36, is the arrival of truck 2 (ARCAM), which took 73.36 minutes for daily maintenance and the trip to the chipping site. The chipper is available and begins loading truck 2. This activity will last until 135.98.

At 135.98 chipping is terminated (DECHI). The truck leaves to deliver its load and will return (code 7 - ARCAM) at 255.74, meaning that it will take 119.76 (255.74 - 135.98) minutes to make the delivery. As for the chipper, its knives are being changed (code 5 - CHGCOU). This activity will be completed at 165.98.

Truck 3 arrives at the site at 143.59 and waits for the chipper (code 12), which is unavailable while the knives are being changed.

At 165.98 the knives have been changed (CHGCOU) and chipping resumes. Truck 3's waiting time is thus 22.39 minutes (165.98 - 143.59).

At 210.78 chipping is terminated (DECHI). Truck 3 leaves to deliver its load and will return (code 7 - ARCAM) at 327.28. The chipper waits for a truck (code 11).

The next event is the arrival of truck 2 (ARCAM) at 255.74. Chipping resumes and the truck is fully loaded at 306.32, or the next event. At 306.32 truck 2 leaves to deliver its load and the chipper is put on hold.

Truck 3 returns to the chipping site at 327.28, thereby terminating the chipper's wait.

At 390.44 truck 3 is loaded and leaves the site. The chipper is put on hold.

Truck 2 returns at 418.75; chipping resumes until 463.55.

The next event is the termination of chipping at 463.55. Truck 2 will deliver its load but will not return to the site (indicated by HR 6000). It will have completed its delivery and thus its shift at 541.00. The chipping knives are changed (code 5), which takes until 493.55.

At 493.55 the knives have been changed and as no truck has returned, the chipper is put on hold.

Truck 3 arrives at 509.14; chipping resumes and will last until 584.14.

At 584.14 truck 3 is fully loaded and will deliver its load and terminate its shift at 647.00. The chipper immediately terminates its shift.

Based on the time the shift begins and its duration (540 minutes), the time it ends can be established as follows:

-chipper: 45 + 540 = 585;
-truck 2: 0 + 540 = 540;
-truck 3: 90 + 540 = 630.

The trace shows that the chipper did indeed complete its shift at 584.00. In this case there is no overtime and no operational delay occurred to end the shift ahead of schedule.

Truck 2 completed its shift at 541.00. The above comments for the chipper apply here as well.

Truck 3 completed its shift at 647.00 and thus worked 17 minutes overtime (647.00 - 630.00); the operator will be paid a half-hour overtime.

CHAPTER 4
SAMPLE SIMULATION

This chapter presents an example of the simulation of a chipping operation in which the skidders stack the trees at the chipping site when there is no space at the chipper itself.

Skidding is handled by a wheeled forwarder and two chain skidders. Chipping is handled by a Morbark 22 chipper. Deliveries are made by two trucks rigged with 14-metre semi-trailers featuring a load capacity of 28 green tons.

The relevant data and the results produced by the simulation model are presented in the following order:

a) Calculation module

Input data:

- General Input Data;
- Basic Data for Each Logging Machine;
- Basic Data for Each Truck Type.

Results:

- Machine Operating Cost.

b) Simulation module

Input data:

- Description of Chipping Operation and Logging Conditions;
- Data for Each Machine;
- Time Duration of Activities in Minutes.

Results:

- Trace for Day 1 (partial);
- Occupation of Machines in Hours (Table for Day 1);
- Breakdown of Costs (Table for Day 1);

-Occupation of Machines in Hours (Average Values per Day for Three Days);

-Breakdown of Costs (Average Values per Day for Three Days);

-Statistics on Productivity.

Reproduction of Input Data
and Results of
CALCULCOUT Calculation Module

GENERAL INPUT DATA

INVESTMENT COSTS.

UNIFORM ANNUAL DEPRECIATION (1 IF APPLICABLE)	:	1.00
LEASING (1 IF APPLICABLE)	:	
- LEASING PERIOD IN YEARS	:	
- INTEREST RATE o/o	:	
RESIDUAL VALUE - o/o OF PURCHASE PRICE	:	30.00
INTEREST RATE APPLICABLE TO AVERAGE INVESTMENT	:	15.00

SALARIES, FRINGE BENEFITS AND MISCELLANEOUS COSTS.

HELPERS HOURLY RATE $	:	8.00
OPERATORS HOURLY RATE $	:	9.00
MECHANICS HOURLY RATE $	:	10.00
FRINGE BENEFITS o/o OF HOURLY RATES	:	22.00
COST OF PARTS FOR LIFE OF MACHINE (o/o)	:	75.00
MECHANICAL SERVICE HOURLY RATE $	:	15.00
FUEL COST - $ PER UNIT OF VOLUME	:	0.45
INSURANCE COST PER YEAR - o/o OF PURCHASE PRICE	:	3.00
HOURS OF WORK PER SHIFT	:	9.00

MISCELLANEOUS INPUTS.

MEASUREMENT UNIT (ACCORDING WITH THE SPECIFIED CODE)	:	5.00
FUEL UNIT OF VOLUME	:	1.00
NUMBER OF DIFFERENT LOGGING MACHINES	:	3.00
NUMBER OF DIFFERENT TRUCKS	:	1.00

BASIC DATA FOR EACH LOGGING MACHINE

IDENTIFICATION.				
REFERENCE NO.	:	1.00	2.00	3.00
FUNCTION CODE	:	1.00	1.00	2.00
CHARACTERISTICS.				
PURCHASE PRICE 1000$	:	60.00	40.00	250.00
RESIDUAL VALUE o/o	:			
LEASING PERIOD	:			
MACHINE LIFE IN 1000 PMH	:	12.00	12.00	12.00
SCHEDULED MACHINE HOURS PER YEAR	:	1800.00	1800.00	1800.00
UTILIZATION RATE o/o	:	80.00	85.00	65.00
ANNUAL EXPENSES.				
INSURANCE $/YEAR	:			
LICENCE $/YEAR	:			
OTHERS $/YEAR	:	1000.00	1000.00	2000.00
CURENT EXPENSES.				
REPAIR HOURS/PMH	:	0.15	0.12	0.15
PARTS COSTS:o/o OF PURCHASE PRICE	:			
$ PER PMH	:			
$ PER YEAR	:			
LUBRICANTS $/PMH	:	1.50	1.00	4.00
OTHERS $/PMH	:			
FUEL CONSUMPTION PER PMH	:	9.00	9.00	45.00
LABOUR.				
NO OF HELPERS	:			1.00
HELPERS HOURLY RATE	:	8.00	8.00	8.00
NO OF OPERATORS	:	1.00	1.00	1.00
OPERATOR HOURLY RATE	:	9.00	9.00	9.00
PRODUCTIVITY.				
PRODUCTIVITY PER PMH	:	7.00	5.00	24.00

BASIC DATA FOR EACH TRUCK TYPE

IDENTIFICATION.

REFERENCE NO.	:	4.00
FUNCTION CODE	:	3.00

CHARACTERISTICS.

PURCHASE PRICE 1000$	:	80.00
RESIDUAL VALUE o/o	:	
LEASING PERIOD	:	
MACHINE LIFE IN 1000 PMH	:	12.00
SCHEDULED MACHINE HOURS PER YEAR	:	2000.00
UTILIZATION RATE o/o	:	85.00

ANNUAL EXPENSES.

INSURANCE $/YEAR	:	3500.00
LICENCE $/YEAR	:	1500.00
OTHERS $/YEAR	:	1500.00

CURENT EXPENSES.

REPAIR HOURS/PMH	:	0.15
PARTS COSTS:o/o OF PURCHASE PRICE	:	
$ PER PMH	:	
$ PER YEAR	:	
LUBRICANTS $/PMH	:	1.00
OTHERS $/PMH	:	
DISTANCE PER FUEL UNIT	:	1.60
NO OF TIRES PER TRUCK	:	22.00
PURCHASE PRICE PER TIRE	:	450.00
TIRE LIFE IN 1000 KM. OR MILES	:	80.00
OPERATOR HOURLY RATE	:	9.00

PRODUCTIVITY.

TRUCK LOAD	:	28.00
TRUCKING DISTANCE (ONE WAY)	:	40.00
AVERAGE SPEED	:	53.00
LOADING AND UNLOADING TIME, HOURS	:	1.25

MACHINE OPERATING COST

	IDENTIFICATION			
REFERENCE NO	1	2	3	4
FUNCTION	SKID	SKID	CHIPP	TRUCK
SCHEDULED HOURS/YEAR	1800	1800	1800	2000
UTILIZATION RATE (o/o)	80	85	65	85
PURCHASE COST 1000$	60	40	250	80
AVERAGE INVEST. 1000$	42	28	171	56
	ANNUAL EXPENDITURES ($/DAY)			
DEPRECIATION	26.25	17.50	87.50	35.87
CAPITAL COST	31.22	20.81	128.44	37.67
INSURANCE AND OTHERS	14.00	11.00	47.50	29.15
TOTAL $/DAY	71.47	49.31	263.44	102.69
TOTAL $/PMH	9.93	6.45	45.03	13.42
	CURRENT EXPENDITURES ($/PMH)			
MECHANICAL SERVICE	2.25	1.80	2.25	2.25
PARTS	5.00	3.33	20.83	6.67
TIRES				3.59
FUEL	4.05	4.05	20.25	8.56
OTHERS	1.50	1.00	4.00	1.00
TOTAL $/PMH	12.80	10.18	47.33	22.07
	LABOUR EXPENDITURES			
$/DAY	98.82	98.82	186.66	98.82
$/PMH	13.72	12.92	31.91	12.92
	TOTAL EXPENDITURES			
$/DAY	262.45	226.03	727.00	370.31
$/PMH	36.45	29.55	124.27	48.41
	PRODUCTIVITY			
G T /DAY	50.40	38.25	140.40	77.62
G T /PMH	7.00	5.00	24.00	10.15
	COST PER GREEN TON			
ANNUAL EXPENSES	1.42	1.29	1.88	1.32
CURRENT EXPENSES	1.83	2.04	1.97	2.17
SUB-TOTAL	3.25	3.33	3.85	3.50
LABOUR	1.96	2.58	1.33	1.27
TOTAL	5.21	5.91	5.18	4.77

Reproduction of Input Data
and Results of
SIMULATION Module

PROJECT: CABANO
SIMULATION: 1 (1 FORWARDER, 2 SKIDDERS, 2 TRUCKS)
DATE: 3/1/1983

DESCRIPTION OF CHIPPING OPERATION AND LOGGING CONDITIONS

STATIONARY CHIPPER WITH A STORAGE PILE CLOSE TO CHIPPER; NO SKIDDERS WAITING.

MACHINES

SKIDDERS	TYPE:	1	FORWARDER JOHN-DEERE (ONE)
	TYPE:	2	SKIDDER (TWO)
CHIPPER	TYPE:		MORBARK MODEL 22
TRUCKS	TYPE:	1	SEMI-TRAILER 14 METERS (TWO)

DESCRIPTION OF STAND AND LOGGING SITE:

STAND	:	PET A/3 J
CUTTING TECHNIQUE	:	CUT OVER
TREES HARVESTED PER HECTARE	:	8000
VOLUME LOGGED PER HECTARE	:	150 GREEN TONS
TERRAIN CHARACTERISTICS: - SLOPE IN o/o	:	15
- GROUND BEARING CAPACITY	:	SOLID
- GROUND MOISTURE	:	NORMAL
TRUCKING DISTANCE	:	40 KM

CHARACTERISTICS OF THE SIMULATION

DAYS OF SIMULATION (NJAS)	:3
PRESENTATION OF DAILY REPORT FOR DAYS (IMPRQ)	:1
TRACE OF ACTIVITIES PRESENTED FOR DAYS (TRAJR)	:1
BIOMASS MEASUREMENT UNIT (ACCORDING TO SPECIFIED CODE)	:G T
MAXIMUM AMOUNT OF WOOD THAT COULD BE STORED AT CHIPPER (BIOMAX)	:15
WOOD IS REHANDLED FROM STORAGE PILES WHEN AMOUNT OF WOOD AT CHIPPER IS LESS THAN (BIOAP)	:5
AMOUNT OF WOOD STORED CLOSE TO CHIPPER SITE AT BEGINNING OF SIMULATION (BIOD)	:10
AMOUNT OF WOOD STORED AT CHIPPER AT BEGINNING OF SIMULATION (BIOR)	:25
TRUCK LOADS CHIPPED WITH SAME SET OF KNIVES (INTCOUN)	:4
WORKING MINUTES PER SHIFT (JOUR)	:540
OVERTIME PREMIUM AS A o/o OF THE REGULAR RATE (PRIME)	:50
FRINGE BENEFITS, AS A o/o OF SALARIES (BENMARG)	:22

COMMENTS

DATA FOR EACH MACHINE (ENTREE)

MACHINE FUNCTION	MACHINE TYPE	STARTING TIME (MIN)	N.BREAK-DOWN PER 000 CYCL	LOAD PER CYCLE (G T)	**	MACHINE COSTS: OWNERSHIP COSTS ($/DAY)	OPERATING COSTS: ACT. A ($/FMH)	OPERATING COSTS: ACT. B ($/FMH)	OPERATING COSTS: ACT. C ($/FMH)	OPERATOR'S SALARY ($/HR)
SKIDDER	1	45	40	3.50	0	72.00	12.80	12.80		9.00
SKIDDER	2	45	40	1.50	1	49.00	10.20	10.20	10.20	9.00
SKIDDER	2	45	40	1.50	1	49.00	10.20	10.20	10.20	9.00
CHIPPER	1	45	60		0	263.00	47.35	47.35		17.00
TRUCK	1	0	50	28.00	165	103.00	22.00	22.00		9.00
TRUCK	1	90	50	28.00	165	103.00	22.00	22.00		9.00

** SKIDDERS: SET TO 1 WHEN UNIT TYPE CAN REHANDLE WOOD AT CHIPPER SITE.
CHIPPER: NOT APPLICABLE.
TRUCKS: MINIMUM TIME (MINUTES) REQUIRED AT THE END OF A SHIFT TO PRODUCE ONE MORE LOAD.

	ACTIVITY A	U.MEASURE	ACTIVITY B	U.MEASURE	ACTIVITY C	U.MEASURE
SKIDDER	SKIDDING FROM STUMP TO CHIPPER	G T	SKIDDING FROM STUMP TO A STORAGE PILE CLOSE TO CHIPPER	G T	REHANDLING FROM STO-RAGE PILE TO CHIPPER	G T
CHIPPER	CHIPPING	G T	CHANGING KNIVES	NO OF OCCURENCES	NOT APPLICABLE	
TRUCK	LOADING	G T	TRUCKING AND UNLOADING	G T	NOT APPLICABLE	

TIME DURATION OF ACTIVITIES IN MINUTES (DURACT)

MACHINE		ACTIVITY		PROBABILITY	PARAMETERS			
FCT	TYPE	CODE	DESCRIPTION	DISTRIBUTION	1	2	3	4
SKIDDER	1	1	SKIDDING CYCLE	NRML	30.0	5.0	12.0	45.0
SKIDDER	1	4	BREAKDOWN	EXPO	40.0	15.0	120.0	
SKIDDER	1	5	MAINTENANCE AND START-UP AT BEGINNING OF SHIFT	UNFR	15.0	30.0		
SKIDDER	2	1	SKIDDING CYCLE	NRML	18.0	4.0	10.0	30.0
SKIDDER	2	4	BREAKDOWN	EXPO	40.0	15.0	120.0	
SKIDDER	2	5	MAINTENANCE AND START-UP AT BEGINNING OF SHIFT	UNFR	15.0	30.0		
SKIDDER	2	2	REHANDLING CYCLE	NRML	8.0	2.0	5.0	12.0
CHIPPER	1	1	CHIPPING (CHIPPING TIME PER UNIT)	NRML	2.5	0.5	1.8	4.0
CHIPPER	1	2	CHANGING KNIVES	AVGE	30.0			
CHIPPER	1	4	BREAKDOWN	EXPO	40.0	15.0	120.0	
CHIPPER	1	5	MAINTENANCE AND START-UP AT BEGINNING OF SHIFT	UNFR	15.0	30.0		
TRUCK	1	1	DELIVERY AND RETURN TRIP TO CHIPPING SITE	UNFR	90.0	150.0		
TRUCK	1	2	DELIVERY TO THE MILL WITH NO RETURN TO CHIPPING SITE	UNFR	60.0	90.0		
TRUCK	1	3	EMPTY TRIP TO CHIPPING SITE (FIRST TRIP OF THE DAY)	UNFR	35.0	55.0		
TRUCK	1	4	BREAKDOWN	EXPO	40.0	15.0	120.0	
TRUCK	1	5	MAINTENANCE AND START-UP AT BEGINNING OF SHIFT	UNFR	15.0	30.0		

PROBABILITY DISTRIBUTIONS CODES

PROB. DISTRIBUTION	PARAMETERS			
AVERAGE	MEAN	-----	-----	-----
NORMAL	MEAN	STD. DEVIATION	MINIMUM	MAXIMUM
UNIFORM	MINIMUM	MAXIMUM	-----	-----
EXPONENTIAL	MEAN	MINIMUM	MAXIMUM	-----

TRACE FOR DAY 1

```
TIME: 61.96
   ACTIVITY: CDEBAR
   SKIDDER          2 2    1 HR   74.08
TIME: 70.42
   ACTIVITY: CHGCOU
   CHIPPER          4 1   11 HR  ¯70.42
TIME: 71.63
   ACTIVITY: CDEBAR
   SKIDDER          1 1    1 HR  100.67
TIME: 72.18
   ACTIVITY: CDEBAR
   SKIDDER          3 2    1 HR   94.35
TIME: 74.0799
   ACTIVITY: DEBAR
   SKIDDER          2 2    1 HR   99.02
TIME: 78.39
   ACTIVITY: ARCAM
   CHIPPER          4 1    4 HR  104.46
   TRUCK            5 1    4 HR  104.46
TIME: 94.3523
   ACTIVITY: DEBAR
   SKIDDER          3 2    2 HR  101.04
TIME: 99.0216
   ACTIVITY: DEBAR
   SKIDDER          2 2    1 HR  122.60
TIME: 100.6675
   ACTIVITY: DEBAR
   SKIDDER          1 1    1 HR  130.67
TIME: 101.0407
   ACTIVITY: APPROCHE
   SKIDDER          3 2    2 HR  112.09
TIME: 104.4577
   ACTIVITY: DECHI
   CHIPPER          4 1    4 HR  120.35
   TRUCK            5 1    4 HR  120.35
TIME: 112.0888
   ACTIVITY: APPROCHE
   SKIDDER          3 2    2 HR  119.41
TIME: 119.40.62
   ACTIVITY: APPROCHE
    SKIDDER         3 2    2 HR  129.27
TIME: 120.3544
   ACTIVITY: DECHI
   CHIPPER          4 1    4 HR 125 .75
   TRUCK            5 1    4 HR  125.75
TIME: 122.59.87
   ACTIVITY: DEBAR
   SKIDDER          2 2    1 HR  140.97
TIME: 125.7444
   ACTIVITY: DECHI
   CHIPPER          4 1    4 HR  128.77
   TRUCK            5 1    4 HR  128.77
TIME: 128.7741
   ACTIVITY: DECHI
   SKIDDER          4 1   10 HR ¯128.77
   TRUCK            5 1   10 HR¯128.77
```

PROJECT: CABANO SIMULATION: 1 (1 FORWARDER, 2 SKIDDERS, 2 TRUCKS) DATE: 25/05/82

OCCUPATION OF MACHINES IN HOURS

TABLE FOR DAY 1

MACHINE				PRODUCTIVE TIME			WAITING		DELAYS		HOURS WORKED		UTILI-SATION	AVAILA BILITY	PRODUCTION			COSTS
	REF	FCT	TYP	ACT. A	ACT. B	ACT. C	CSE 1	CSE 2	MECA.	OTHER	MACH.	MEN			ACT. A (G T)	ACT. B (G T)	ACT. C (G T)	($)
SKIDDER																		
	1	1	1	8.57					0.69		9.26	9.5	93	93	60			287.28
	2	1	2	6.40	0.34	0.91			1.36		9.00	9.0	85	85	29	2	11	225.79
	3	1	2	6.57	0.31	1.66			0.45		9.00	9.0	95	95	32	2	18	235.00
AVERAGE				7.18	0.22	0.86			0.83		9.09	9.2			40	1	10	249.36
PERCENTAGE				79	2	9			9		100		91	91				
CHIPPER																		
	4	2	1	5.57	0.50		0.06	1.79	0.42	0.65	9.00	9.0	67	95	140	1		737.17
PERCENTAGE				62	6		1	20	5	7	100		67	95				
TRUCK																		
	5	3	1	3.42	5.57		0.61	0.06	0.47		10.13	10.5	89	95	84	84		419.98
	6	3	1	2.15	4.68				0.48	1.70	9.00	9.0	76	95	56	56		351.94
AVERAGE				2.79	5.12		0.30	0.03	0.47	0.85	9.57	9.8			70	70		385.96
PERCENTAGE				29	54		3		5	9	100		83	95				

	WAITING CAUSE 1	WAITING CAUSE 2
SKIDDER	SURPLUS OF WOOD AT CHIPPER	DOES NOT APPLY
CHIPPER	SHORTAGE OF WOOD	NO TRUCK
TRUCK	CHIPPER IS BUSY	SHORTAGE OF WOOD

PROJECT: CABANO   SIMULATION: 1 (1 FORWARDER, 2 SKIDDERS, 2 TRUCKS)   DATE: 25/05/82

BREAKDOWN OF COSTS

TABLE FOR DAY 1

MACHINE			EXPENSES PER DAY				COST PER GREEN TON									COST PER GREEN TON CHIPPED		
				MACHINE		TOTAL	ACTIVITY A			ACTIVITY B			ACTIVITY C					
REF	FCT	TYP	LABOUR	OWNER	OPER.		LAB.	MACH.	TOTAL	LAB.	MACH.	TOTAL	LAB.	MACH.	TOTAL	LAB.	MACH.	TOTAL
SKIDDER																		
1	1	1	106	72	110	287	1.77	3.05	4.83									
2	1	2	99	49	78	226	2.90	3.73	6.63	2.90	3.73	6.63	1.12	1.44	2.56			
3	1	2	99	49	87	235	2.41	3.32	5.73	2.41	3.32	5.73	1.07	1.47	2.54			
SUB-TOTAL:			303	170	275	748										2.17	3.18	5.34
AVERAGE:							2.21	3.29	5.50	2.66	3.53	6.18	1.09	1.46	2.55			
CHIPPER																		
4	2	1	187	263	288	737	1.22	3.61	4.83	15.37	45.33	60.70				1.33	3.93	5.27
TRUCK																		
5	3	1	119	103	198	420	0.54	1.36	1.90	0.88	2.22	3.10						
6	3	1	99	103	150	352	0.56	1.42	1.98	1.21	3.10	4.31						
SUB-TOTAL:			218	206	348	772										1.56	3.96	5.51
AVERAGE:							0.55	1.39	1.93	1.01	2.57	3.58						
TOTAL			708	639	910	2257										5.06	11.07	16.12

PROJECT: CABANO | SIMULATION: 1 (1 FORWARDER, 2 SKIDDERS, 2 TRUCKS) | **DATE: 25/05/82**

OCCUPATION OF MACHINES IN HOURS

AVERAGE VALUES PER DAY FOR 3 DAYS

MACHINE			PRODUCTIVE TIME			WAITING		DELAYS		HOURS WORKED		UTILI- SATION	AVAILA BILITY	PRODUCTION			COSTS
REF	FCT	TYP	ACT. A	ACT. B	ACT. C	CSE 1	CSE 2	MECH.	OTHER	MACH.	MEN			ACT. A	ACT. B	ACT. C	
														(G T)	(G T)	(G T)	($)
SKIDDER																	
1	1	1	8.30	0.66				0.82		9.77	10.0	92	92	57	5		298.92
2	1	2	6.15	0.58	1.13			1.60		9.47	9.7	83	83	30	3	12	237.11
3	1	2	7.05	0.42	0.55			1.43		9.45	9.7	85	85	34	2	6	238.65
AVERAGE			7.17	0.55	0.56			1.28		9.56	9.8			40	3	6	258.23
PERCENTAGE			75	6	6			13		100		87	87				
CHIPPER																	
4	2	1	5.79	0.50		0.72	1.66	0.38	0.22	9.26	9.3	68	96	140	1		755.95
PERCENTAGE			63	5		8	18	4	2	100		68	96				
TRUCK																	
5	3	1	3.48	6.11		0.25	0.46	0.75		11.06	11.3	87	93	84	84		444.26
6	3	1	2.31	4.43		0.37	0.25	0.40	1.24	9.00	9.0	75	96	56	56		350.06
AVERAGE			2.89	5.27		0.31	0.36	0.57	0.62	10.03	10.2			70	70		397.16
PERCENTAGE			29	53		3	4	6	6	100		81	94				

	WAITING CAUSE 1	WAITING CAUSE 2
SKIDDER	SURPLUS OF WOOD AT CHIPPER	DOES NOT APPLY
CHIPPER	SHORTAGE OF WOOD	NO TRUCK
TRUCK	CHIPPER IS BUSY	SHORTAGE OF WOOD

PROJECT: CABANO SIMULATION: 1 (1 FORWARDER, 2 SKIDDERS, 2 TRUCKS) DATE: 3/1/1983

BREAKDOWN OF COSTS

AVERAGE VALUES PER DAY FOR 3 DAYS

MACHINE			EXPENSES PER DAY				COST PER GREEN TON									COST PER GREEN TON CHIPPED		
				MACHINE		TOTAL	ACTIVITY A			ACTIVITY B			ACTIVITY C					
REF	FCT	TYP	LABOUR	OWNER	OPER.		LAB.	MACH.	TOTAL	LAB.	MACH.	TOTAL	LAB.	MACH.	TOTAL	LAB.	MACH.	TOTAL
SKIDDER																		
1	1	1	112	72	115	299	1.82	3.02	4.85	1.77	2.93	4.70						
2	1	2	108	49	80	237	2.81	3.37	6.18	2.67	3.20	5.87	1.29	1.55	2.84			
3	1	2	108	49	82	239	2.79	3.38	6.16	2.83	3.44	6.27	1.24	1.51	2.75			
SUB-TOTAL:			328	170	277	775										2.34	3.19	5.53
AVERAGE:							2.34	3.21	5.55	2.27	3.12	5.39	1.28	1.54	2.81			
CHIPPER																		
4	2	1	195	263	298	756	1.28	3.69	4.97	15.52	44.58	60.10				1.39	4.01	5.40
TRUCK																		
5	3	1	130	103	211	444	0.56	1.36	1.92	0.99	2.38	3.37						
6	3	1	99	103	148	350	0.60	1.54	2.14	1.16	2.95	4.11						
SUB-TOTAL:			229	206	359	794										1.64	4.04	5.67
AVERAGE:							0.58	1.43	2.01	1.06	2.61	3.67						
TOTAL			752	639	934	2325										5.37	11.23	16.61

PROJECT: CABANO SIMULATION: 1 (1 FORWARDER, 2 SKIDDERS, 2 TRUCKS) DATE: 27/05/82

STATISTICS ON PRODUCTIVITY

NUMBER OF DAYS SIMULATED: 3

VARIABLES	NO OBS	MEAN	STD.DEV.	MINIMUM	MAXIMUM
TRUCKS WAITING FOR CHIPPER	3	37.40	28.93	8.93	66.76
CHIPPER WAITING FOR TRUCK	12	24.86	23.98	5.21	89.81
CHIPPER WAITING FOR SKIDDER	25	5.17	3.98	0.08	13.81
SKIDDERS WAITING TIME					
BIOMASS CHIPPED PER DAY IN GREEN TONS	3	140.00		140.00	140.00
DAILY COST PER UNIT CHIPPED	3	16.61	0.46	16.12	17.04

4.1 Comments on the sample simulation

The cost calculation module was used to estimate ownership costs (annual expenditures) and operating costs (current expenditures) for the machines processed by the simulation module. For the chipper in the simulation we used an ownership cost of $263.00 per day (estimated at $263.44 by the calculation module) and an operating cost of $47.35 per PMH (estimated at $47.33).

The calculation module also estimates the production cost per unit (the green ton in our example), which amounts to $5.18 for the chipper. The costs obtained by the simulation module are apt to differ since the utilisation rate obtained from the simulation is rarely the same as that used for the computations and since the productivity of the machines varies during simulation. In this case, the chipping cost obtained through simulation is $5.40 per green ton (see Breakdown of Costs table for the three days simulated), which comes to $0.22 or 4% more. The estimate arrived at through simulation is the more reliable of the two.

The chipper utilisation rate was 68% by simulation, compared with 65% used in the calculations. Mean productivity was 22.3 green tons per PMH [140 ÷ (5.79 + 0.50)], compared with 24 green tons.

The same comparisons could be made for the other machines.

Let us now examine the individual simulation module printouts and derive their main conclusions.

Trace

Only the beginning of the trace for day 1 is presented here. The portion shown allows for a number of observations.

- The chipper was ready for work at 70.42 (CHGCOU) and the first truck arrived at 78.39 (ARCAM). The chipper thus waited 7.97 minutes. Apparently, the schedules of the chipper and the first truck are well co-ordinated. Analysis of the remainder of the trace (not shown) shows the first truck leaving the chipper at 139.53 and the second truck arriving at 106.56. This time the chipper waited 21.03 minutes. It would be good to advance the departure of the second truck by 15 minutes. This is all the more advisable as this truck loses more than an hour at the end of the shift for lack of time to deliver a third load (see Occupation of Machines table, Delays-Other column).

- Shortly after chipping began, a skidder was assigned to rehandle wood from the storage pile at the chipping site. The first load rehandled arrived at the chipper at 101.04 (APPROCHE). Skidder 3, a type 2 machine, was assigned to rehandling.
- At 128.77 chipping of the wood on hand was completed (DECHI) and the chipper and the truck were put on hold (activity code 10, negative time). The wait was very short since skidder 3, assigned to rehandling, arrived at 129.27. The remainder of the trace (not shown) shows that no further wood shortages occurred before the truck was fully loaded. Apparently, the three skidders had trouble supplying the chipper. The next tables will enable us to ascertain whether there is sufficient skidding capacity.

Occupation of Machines - Table for Day 1

The Productive Time columns for the skidders give the machines' activities as follows:

- 79% of the shift skidding wood from the stump to the chipper (ACT. A);
- 2% of the shift skidding wood from the stump to the storage pile at the chipping site (ACT. B);
- 9% of the shift rehandling wood from the storage pile to the chipper (ACT. C).

According to the Production columns, 121 green tons (60 + 29 + 32) were skidded from the stump to the chipper (ACT. A), 4 green tons (2 + 2) were added to the storage pile (ACT. B) and 29 green tons (11 + 18) were rehandled from the storage pile to the chipper (ACT. C). The storage pile, which held 25 green tons at the start of the shift (BIOR), is thus empty.

The chipper spent 62% of the shift chipping (ACT. A) and 6% changing knives (ACT. B). One hundred forty green tons were produced, for a mean productivity of 23.1 green tons per PMH [140 ÷ (5.57 $\pm$ 0.50)].

Time lost in waiting is 1.85 hours, or 21% of the shift, including 1% for lack of wood and 20% for lack of trucks. Based on the results for this day, there is no cause to add more skidders. An operating delay of 0.65 hour (7%) occurred at the end of the shift as the last truck completed loading at that time (Delays-Other). This lost time in the aggregate reduces the chipper utilisation rate to 67%, whereas the availability rate stands at 95%.

The truck data show that the vehicles spend 29% of the shift loading (ACT. A) and 54% delivering their load, for a utilisation rate of 83%.

The trucks lost only 3% of this time waiting. Only the truck that began first had to wait.

The first truck delivered three loads (84 ÷ 28) and had to work overtime. The second truck delivered only two loads (56 ÷ 28) and terminated its shift 1.70 hours ahead of schedule. The mean time for loading and delivering was 3.16 productive hours, for a mean productivity of 8.86 green tons per PMH (28 ÷ 3.16), compared with 10.15 green tons estimated by the calculation module.

For better evaluation of this operation, we will examine the Occupation of Machines table for the entire period simulated.

Occupation of Machines - Average Values per Day

The breakdown of skidder productive time among activities A, B, and C remained substantially the same for the entire period simulated as for the first day, i.e. 75%, 6%, and 6% compared with 79%, 2%, and 9%. It is normal to observe a relative drop in the time spent on activity C (rehandling) since the storage pile was empty at the end of the first day.

The skidders worked less overtime the first day than was averaged for the three days simulated.

According to the Production columns, during the period simulated 363 green tons [(57 + 30 + 34) x 3] were skidded from the stump to the chipper and 30 green tons [(5 + 3 + 2) x 3] had to be stored and rehandled, amounting to 7.6% [30 ÷ (363 + 30)] of all wood skidded. This amount does not seem excessive; it raises the mean skidding cost by $0.21 per green ton, derived by multiplying the average rehandling cost, $2.81 per green ton (see cost breakdown table) by the percentage rehandled, i.e. 7.6%.

This additional cost can be avoided by having the skidders wait when there is no space near the chipper. But having no storage pile at the chipping site would increase chipper time lost because of shortage of wood, thereby augmenting chipping and trucking costs. Simulation of this operating mode would make it possible to determine which of the alternatives is more advantageous.

The chipper utilisation rate for the three days simulated was 68%, compared with 67% for day 1. As regards productive time, there is thus no significant difference between day 1 and the three days as a whole.

However, the breakdown of unproductive time is an entirely different matter. The table shows average waiting time attributable to shortage of biomass as 8%, compared with 1% for day 1. The 25 green tons stacked at the chipping site at the start of the first day accounts in part for this difference. The waiting time attributable to a lack of trucks at the site is much the same, or 18% as against 20%. Mechanical delays are similar, while Delays-Other indicates a 5% reduction, or 7% for day 1 compared with 2% for the entire period simulated. This is consistent with the increase in time lost through waiting since the more waits there are, the later the chipper completes its work. In this connection, we observe that the chipper worked overtime.

The two trucks made the same number of runs per day, three for the first truck to start and two for the other. Truck waiting time attributable to the chipper remained unchanged at 3%. Waiting time because of shortage of wood rose from 0 to 4%. The delays at the end of the day were reduced, dropping from 9% to 6%. Only the second truck, which delivered only two loads per day, completed its shift ahead of schedule. The first truck had to work overtime to deliver three loads.

Analysis of the two Occupation of Machines tables (day 1 and entire period simulated) reveals a fairly good balance between skidding and chipping capacities. The chipper lost an average 0.72 hour per day because of shortage of wood; 7.6% of the biomass skidded could not be stacked at the chipper. Chipper time lost because of shortage of wood would have been slightly higher had the biomass storage pile (BIOR) been low or empty at the beginning of simulation.

As far as the trucks are concerned, the only practical improvement appears to be the earlier start-up of the second truck. This would reduce somewhat the chipper's time lost because no truck is available and the first truck's time lost because the chipper is busy loading the other truck. The second truck, on the other hand, would lose more time waiting for the chipper, but this would not affect its productivity or costs since it would have less unproductive time at the end of the shift (Delays-Other column).

The second truck cannot deliver a third load without substantially increasing the overtime of the skidders and the chipper, except perhaps if a fourth skidder were added so as to reduce time lost through shortage of biomass. However, the use of a fourth skidder would entail increased rehandling of the biomass (activities B and C).

Breakdown of Costs

The cost breakdown tables (day 1 and period simulated) show the cost of each activity and the distribution of costs between labour and machinery.

It should be pointed out that the skidding cost per green ton chipped is underestimated as it does not include the cost of initial skidding of the stored biomass at the beginning of the simulation (25 green tons). This justifies increasing the average skidding cost by $0.33 per green ton chipped. This adjustment is computed as follows:

-cost of initial skidding of 25 green tons: 25 x $5.55 (average skidding cost) = $138.75;

-cost per green ton chipped $138.75 ÷ (140 x 3) = $0.33.

This adjustment would not have been necessary had the amount of biomass in the storage pile been about the same at the end of simulation as at the beginning. Had the period simulated been longer (10 days or so), the adjustment would be negligible.

If changes are made in the machines or the operating mode and the simulation is then repeated, these tables will allow for comparison of the costs derived from each simulation and identification of the factors that rise or drop.

Statistics on Productivity

According to this table, truck waits for the chipper were infrequent (three times in three days) but varied greatly, from 8.93 to 66.76 minutes. Having the second truck start earlier risks increasing the number of waits but would shorten their mean duration.

Chipper waits for a truck were much more frequent (12 times in three days), also with widely varying durations, from 5.21 to 89.81 minutes.

Since with each run the truck waits for the chipper or the chipper waits for the truck to arrive, the total frequency of these two waiting causes equals the number of loads delivered (15 in this case). Moreover, as the truck loading time, 1.16 hours in our example (2.89 ÷ 2.5), is longer than the trucking time, 2.11 hours (5.27 ÷ 2.5), it is normal that the chipper waits more often than the trucks. The deviation between loading and trucking times does not appear sufficient to warrant the use of a third truck.

During the three days simulated the chipper waited 25 times for a skidder; that waiting time averaged 5.17 minutes, ranging from less than a minute (0.08) to 13.81 minutes. These values point to marginal skidding capacity, which should be increased somewhat so as to cut down on waiting and eliminate some of the overtime.

Skidder waiting time is nil since the operating mode used excludes this possibility.

One hundred and forty green tons were chipped per day, with little variation, as indicated by the minimum and maximum values.

The daily average per unit chipped was $16.61, varying from $16.12 to $17.04. Based on the standard deviation, it can be estimated that a 10-day simulation would evaluate the average chipping cost to within $0.32, for an accuracy of 2%.

4.2 Conclusions

This example gives an idea of the amount of data produced through simulation. It further shows how these data can be used to understand the biomass harvesting operation and pinpoint its weaknesses.

The simulation results discussed above suggest a number of additional simulations.

1. Repetition of our sample simulation after changing the departure time of the second truck to 70 minutes (up from 90 minutes) after the first and elimination of the storage pile (BIOR) at the beginning of simulation.
2. The use of two type 1 skidders (forwarders) and one type 2 skidder to enhance skidding productivity without increasing the number of machines.
3. The addition of a fourth skidder.
4. The addition of a third truck.

CHAPTER 5
USES AND LIMITATIONS OF SIMULATION

The utilisation of the biomass harvesting simulation model has been amply described in the preceding chapters and its many applications for planning such operations have been highlighted. This chapter deals with the use of the model as a training aid and sets out its limitations.

5.1 Simulation as a training aid

The simulation model presented in this report not only aids in planning biomass chipping operations but can also be used to train the foremen who will be supervising such work.

In the context of a training course, the instructor can provide the trainees with the simulation results for a poorly planned operation, then ask them to analyse the data and make the necessary corrections. The trainees' suggestions can be quickly evaluated and the effects demonstrated by means of the simulation model. By starting with simple situations and gradually tackling increasingly difficult problems, the prospective foremen soon gain a sound understanding of how each phase of the operation relates to the others and affects costs. This problem solving approach provides valuable experience that is both difficult and costly to gain in the field. Such training would have the advantage of familiarizing foremen with the simulation model and encouraging them to use it when faced with difficult decisions in the field.

5.2 Limitations of simulation

The biomass harvesting simulation model can be used to analyse only part of the harvesting operation, i.e. that part which is harder to analyse because of the interaction of the machines involved. To complete the comparison of the options analysed through simulation, one must add the cost of the operations that are not simulated. As a rule, the operations listed below fall in this category.

-Felling
-Skidding in some cases
-Site preparation and approach
-Site relocation
-Operation administration and supervision

In a given instance, the use of four skidders may guarantee a steady supply of biomass for the chipper and minimize costs. But that improvement over the results scored with three skidders may still not be sufficient to cover the expense of bringing in a fourth skidder, particularly if only small amounts are harvested at each site.

In another case, the use of a mobile chipper working from a roadside woodpile may be the best method, whereas space limitations at the harvesting site rule out this option or else the costs of preparing the site for this operating mode exceed the potential savings.

The factors for evaluating the costs involved in preparing a site and relocating the machines are indicated in the appendix. This information is merely indicative, for the approach constraints are so variable that each site must be evaluated on its own merit by an expert.

Still, an operation that makes use of extensive equipment, as does the chipping of whole trees, is particularly favored when large amounts of biomass are harvested at each site and the harvesting sites are close together.

To produce valid results, it is not enough that the simulation model faithfully imitate the activities of the machines. Accurate knowledge of the duration of those activities and machine productivities is also required.

In the absence of a reliable reference base, simulation can still provide useful information on certain aspects of the operation. For one, it can serve to verify the number of skidders required to supply a chipper, even where the productivity of these two types of machines is not clearly established. In this case the simulation is repeated several times, changing machine productivity in line with the most probable values. The number of skidders required will be the number proving most satisfactory in the most productivity scenarios. One should bear in mind that under these circumstances the production costs obtained are far less precise than when machine productivity is known.

5.3 Conclusions

Given its capability of accurately reproducing a given operation, simulation allows for a series of trials whereby the operation can be analysed and understood at relatively low cost, compared with the cost of testing in the field. It is a powerful, flexible planning, testing, and training tool.

APPENDIX 1

GUIDELINES FOR ESTIMATING SITE PREPARATION AND MACHINE RELOCATION COSTS

Estimation of Site Preparation Costs

A caterpillar tractor with 100 to 140 HP is sufficient to prepare the approach to most private woodlots. As a rule, this preparation consists of clearing and leveling the mineral soil and providing proper drainage of the site. If part of the lot is under crops, it might be necessary to upgrade the forest approach road to accommodate a semi-trailer.

We estimate that site preparation will generally take no more than 4 or 5 hours.

The tractor operating cost can be calculated by the calculation module of the simulation model. It amounts to roughly $35.00 per hour.

Estimation of Machine Relocation Costs

The machines can be moved to the new site by one of the trucks used for hauling the chips. One simply replaces the semi-trailer by a flat-bed truck.

The relocation of each machine will take the truck 90 minutes to 2 hours; production of the machine being moved will be halted for an hour or so.

The costs applicable to the moving truck are derived by multiplying the relocation time for one machine by the number of machines involved and by the truck's hourly operating cost, including the operator pay rate.

Added to the truck cost is the cost of loss of production of the machines being relocated. We estimate the cost of this production loss at the operator pay rate for the time the machine is idle since no operating expenses are incurred during this time.

Following is an evaluation of the relocation of the machines used in the sample simulation in Chapter 4. It is assumed that the relocation of each machine requires two hours of truck time and entails one hour of lost production for each machine.

Total moving truck time: 9 hours
or -2 hours for each skidder: 6 hours
-2 hours for the chipper: 2 hours
-a one-way trip for the semi-trailer: 1 hour

Moving truck costs:

-ownership costs (1 day)	$103.00
-operating costs: $22/PMH x 9 PMH	198.00
-operator: $9/hour x 9 hours x $1.22 (fr. ben.)	99.00
	$400.00

Lost production costs:

-time per machine: 1 hour	
-costs: 4 hours x $9/hour x $1.22 (fr. ben.): $43.92	
-rounded costs	$ 44.00
Grand total	$444.00

As the biomass produced at each site ranges from 200 to 800 green tons harvested on private land, the machine relocation cost can become a fairly important factor.

It should be noted that no relocation cost is attributed to the truck, which is not one of the machines relocated. It is assumed that the truck will complete its last run at the former site and return to the new site without interrupting its normal duty cycle.

APPENDIX 2

PRESENTATION OF THE "CALCULCOUT" MODULE PROGRAM

1. Definition of the calculation program and its functions

The calculation module is stored in the computer's CALCULCOUT workspace and its main program is called CALCOUT. It incorporates many functions, which can be grouped as follows:

- data input functions; enter the data from the input forms and any necessary corrections;
- verification functions: present the storage data in the same format as on the forms;
- calculation functions: perform the calculations;
- result presentation functions: present the results derived by the calculation module.

1.1 Definition of data input functions

DATA INPUT: (LECTURE) Enters and corrects the data recorded on the General Input Data, Basic Data for Each Logging Machine and Basic Data for Each Truck Type forms.

CREA: Called by DATA INPUT to enter the data presented in table format.

1.2 Definition of verification functions

VERIFICATION: Presents the storage data in the same format as on the three forms above.

CORRECTION: Indicates the procedure for correcting erroneous data.

1.3 Definition of calculation functions

UNIFR: Standardizes the format of inputs that may have been entered in different forms.

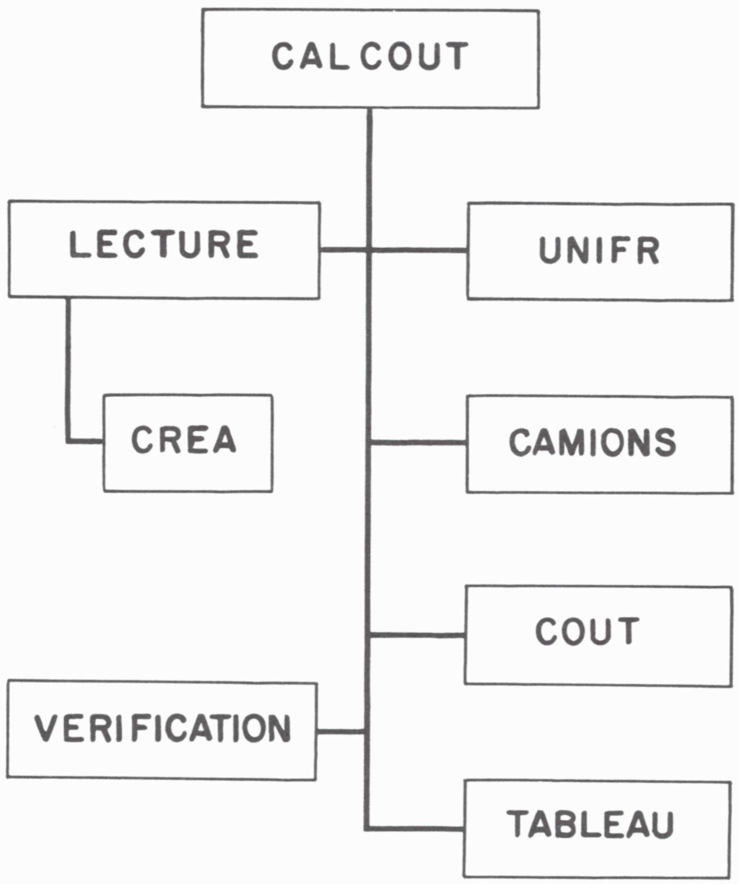
CAMIONS: Executes the calculations pertaining to the trucks.

COUT: Calculates the operating cost of all the machines.

1.4 Definition of result presentation functions

TABLEAU: Produces the calculation module results on one or more 21.6 x 28 cm tables, each of which presents the results for up to six machines.

2- BLOCK DIAGRAM OF CALCOUT PROGRAM



3- CALCULCOUT PROGRAM LISTING

MAIN PROGRAM FOR WORKSPACE CALCULA :

```
     ∇ CALCOUT
[1]    ⍝ CONTROL PROGRAM
[2]    MENU
[3]    '---->  ',NLF
[4]    →(4<A←∊⍞)/0
[5]    →(3=A)/EXEC
[6]    ∊(3↓(PHASE[A;]))
[7]    →2
[8]    EXEC:UNIFR
[9]    CAMIONS
[10]   COUT
[11]   'SET PAPER ON LAST LINE  AND PRESS RETURN'
[12]   Z←⍞
[13]   TABLEAU
     ∇
```

INPUT FONCTIONS :

```
     ∇ LECTURE;LD;N;NC;X
[1]    ⍝   DATA INPUTS MODULE
[2]    ⍝   ACCORDING WITH DATA FORMS
[3]    ⍝
[4]    ⍝   THIS MODULE IS ALSO USED FOR DATA CORRECTIONS
[5]    ⍝
[6]    ⍝
[7]    '1- GENERAL    2- LOGGING MACHINES    3- TRUCKS    4- ALL'
[8]    'YOUR CHOICE ----> ',NLF
[9]    LD←⍎⍞
[10]   →(~((1∊LD)∨(4∊LD)))/BR2
[11]   TR[1;]
[12]   'ACTUAL VALUES:  ';RENG
[13]   'ENTER THE 19 VALUES ON A SINGLE LINE  ( PRESS    RETURN  IF VALUE
       S ARE THE SAME )'
[14]   →(0=⍴X←⍞)/BR2
[15]   RENG←19↑⍎X
[16]   BR2:→(~((2∊LD)∨(4∊LD)))/BR1
[17]   2 1⍴' '
[18]   TR[2;]
[19]   N←RENG[18]
[20]   'ENTER  NUMBER OF COLUMNS REQUIRED (RETURN  IF = ';N;'  )'
[21]   →(0=⍴NC←⍞)/C1
[22]   N←⍎NC
[23]   C1:ENGEX←(23,1↑N)CREA ENGEX
[24]   BR1:→(~((3∊LD)∨(4∊LD)))/0
[25]   2 1⍴' '
[26]   TR[3;]
[27]   N←RENG[19]
[28]   'ENTER NUMBER OF COLUMNS REQUIRED ( PRESS RETURN IF = ';N;'  )'
[29]   →(0=⍴NC←⍞)/C2
[30]   N←⍎NC
[31]   C2:→(0≠N)/CONT
[32]   CAM←26 0⍴0
[33]   'NO DATA REQUIRED'
[34]   →0
[35]   CONT:CAM←(26,N)CREA CAM
     ∇
```

```
    ∇ R←A CREA B;RO;C;DR;D
      ⍝  DATA INPUTS SUB-MODULE
      ⍝ ON MATRIX FORM
      ⍝  CALLED FROM ¨LECTURE¨ MODULE
      ⍝
      B←A↑B
      '(P)REVIOUS     (S)TEP     (T)O END'
      'LINE      DATA'
      C←0
      RO←1↑ρB
      BR:C←C+1
      NBR:'C←1'SI(C≤0)
      'C←RO'SI(C>RO)
      DR←C
      (,('I3'ΔFMT C)),'        ';,B[C;]
      (,('I3'ΔFMT C)),'        ',NLF
      'C←C-2'SI('P'=1↑D←⍞)
      'C←C-1'SI~(∨/(1↑D)='PSTρι.¯ 1234567890')
      'C←C+1'SI('S'=1↑D)
      →(DR≠C)/BR
      →('T'=1↑D)/FIN
      →(~(∧/D∊'.¯ ιρ1234567890'))/NBR
      →(0=ρD)/CT
      B[C;]←∊D
      CT:→(C<RO)/BR
      FIN:R←B
    ∇
```

VERIFICATION FONCTIONS :

```
    ∇ VERIFICATION;TD;T1;DATA;TX;MT;MX;C;LF;MXX;CAT
[1]   ⍝   REPRODUCTION OF INPUT DATA FOR THEIR VERIFICATION
[2]   ⍝
[3]   ⍝
[4]   '1- GENERAL    2- LOGGING MACHINE    3- TRUCK    4- ALL'
[5]   'ENTER  FORM CODE DESIRED'
[6]   DATA←3 5⍴'RENG ENGEXCAM  '
[7]   LF←30 17 17
[8]   CAT←3 6⍴1 7 16 0 0 0 1 3 9 12 19 23 1 3 9 12 0 23
[9]   MT←3 7⍴'MTRENG MTENGEXMTENGEX'
[10]  MX←3 7⍴'MXRENG MXENGEXMXCAM  '
[11]  TD←3↑⎕
[12]  'TD←⍳3'SI 4=1↑TD
[13]  T1←1
[14]  0⍴⍞,⍞←'PLEASE  ADJUST PAPER'
[15]  BR3:→(~T1∊TD)/AT
[16]  5 1⍴' '
[17]  TR[T1;]
[18]  SL[T1;]
[19]  ' '
[20]  MXX←∊MX[T1;]
[21]  →(T1≠3)/CONT
[22]  →(0=¯1↑⍴CAM)/AT
[23]  MXX←(∊MX[2;])[⍳17;],[1]MXX
[24]  CONT:C←1
[25]  BR1:→(~C∊(CAT[T1;]))/BR2
[26]  ' '
[27]  (∊MT[T1;])[((CAT[T1;])⍳C);]
[28]  ((∊MT[T1;])[((CAT[T1;])⍳C;]⍳'.')⍴'-'
[29]  BR2:MXX[C;];('BF8.2'⍕FMT(∊DATA[T1;]))[C;]
[30]  →((1↑⍴MXX)≥C←C+1)/BR1
[31]  ((LF[T1]),1)⍴' '
[32]  AT:→(3≥T1←T1+1)/BR3
    ∇
```

```
    ∇ CORRECTION
[1]   ⍝ HOW TO MAKE CORRECTIONS
[2]   'TO MAKE A CORRECTION'
[3]   'IT IS NECESSARY TO CALL (VIA LE MENU) THE '
[4]   '   MODULE ''INPUT'' AND MAKE CHANGES'
[5]   '   TO APPROPRIATE ITEMS'
    ∇
```

CALCULATION FONCTIONS :

```
    ∇ UNIFR;Y;K
[1]   ⍝  ARRANGE DATA COMING FROM MULTIPLE CHOICES
[2]   ENGCAM←ENGEX[⍳17;],CAM[⍳17;]
[3]   COPER←(28,¯1↑⍴ENGCAM)⍴0
[4]   ⍝  RESIDUAL VALUE
[5]   Y←(ENGCAM[4;]=0)/K←⍳¯1↑⍴ENGCAM
[6]   ENGCAM[4;Y]←RENG[5]
[7]   ENGCAM[4 8 13;]←ENGCAM[4 8 13;]÷100
[8]   ⍝  INSURANCES
[9]   Y←(ENGCAM[9;]=0)/K
[10]  ENGCAM[9;Y]←10×ENGCAM[3;Y]×RENG[14]
[11]  ⍝  PARTS COST
[12]  Y←(ENGCAM[13;]≠0)/K
[13]  ENGCAM[14;Y]←(×/[1]ENGCAM[3 13;Y])÷ENGCAM[6;Y]
[14]  Y←(ENGCAM[15;]≠0)/K
[15]  ENGCAM[14;Y]←ENGCAM[15;Y]÷×/[1]ENGCAM[7 8;Y]
[16]  Y←(ENGCAM[14;]=0)/K
[17]  ENGCAM[14;Y]←(÷/[1]ENGCAM[3 6;Y])×RENG[11]÷100
[18]  ⍝  LEASING PERIOD
[19]  Y←(ENGCAM[5;]=0)/K
[20]  ENGCAM[5;Y]←RENG[3]
[21]  ⍝  HEPERS SALARIES
[22]  Y←(ENGEX[20;]=0)/K←⍳¯1↑⍴ENGEX
[23]  ENGEX[20;Y]←RENG[7]
[24]  ⍝  OPERATORS SALARIES
[25]  Y←(ENGEX[22;]=0)/K
[26]  ENGEX[22;Y]←RENG[8]
[27]  ⍝   TRUCKERS
[28]  Y←(CAM[22;]=0)/⍳¯1↑⍴CAM
[29]  CAM[22;Y]←RENG[8]
    ∇
      ⊣(



    ∇ CAMIONS;TEMPS
[1]   ⍝ CALCULATIONS RELATED TO TRUCKS
[2]   TEMPS←CAM[26;]+2×÷/[1]CAM[24 25;]
[3]   PROD←CAM[23;]÷TEMPS
[4]   CARBUR←(2×÷/[1]CAM[24 18;])+CAM[26;]×(9 2)[RENG[17]]
[5]   CARBUR←CARBUR÷TEMPS
[6]   PNEUX←(×/[1]CAM[19 20;])÷1000×CAM[21;]
[7]   PNEUX←2×CAM[24;]×PNEUX÷TEMPS
    ∇
```

```
     ∇ COUT;Z;ZZ;Y
[1]    ⍝ CALCULATION OF EQUIPMENT OPERATING COST
[2]    COPER[1 2 3 5;]←ENGCAM[1 2 7 3;]
[3]    COPER[4;]←ENGEX[8;],CAM[8;]
[4]    JOURS←⌈ENGCAM[7;]÷RENG[15]
[5]    VIE←⌊0.5+1000×ENGCAM[6;]÷×/[1]ENGCAM[7 8;]
[6]    ⍝  AVERAGE INVESTMENT
[7]    COPER[6;]←((ENGCAM[3;]×VIE+1)+(×/[1]ENGCAM[3 4;])×VIE-1)÷2×VIE
[8]    ⍝  DEPRECIATION
[9]    →(RENG[1]=1)/DEPUNFR
[10]   →(RENG[2]=1)/ACHLOC
[11]   COPER[7 8;]←0
[12]   →ASS
[13]   DEPUNFR:COPER[7;]←(ENGCAM[3;]×1000×(1-ENGCAM[4;]))÷VIE×JOURS
[14]   COPER[8;]←COPER[6;]×RENG[6]×10÷JOURS
[15]   →ASS
[16]   ACHLOC:Z←RENG[4]÷100
[17]   COPER[7;]←(1-ENGCAM[4;])×1000×ENGCAM[3;]×Z×ZZ←(Z+1)*ENGCAM[5;]
[18]   COPER[7;]←COPER[7;]÷JOURS×ZZ-1
[19]   COPER[8;]←0
[20]   ASS:COPER[9;]←(+/[1]ENGCAM[9 10 11;])÷JOURS
[21]   COPER[10;]←+/[1]COPER[9 7 8;]
[22]   COPER[11;]←COPER[10;]÷RENG[15]×ENGCAM[8;]
[23]   ⍝  CURRENT EXPENSES
[24]   COPER[12;]←ENGCAM[12;]×RENG[12]
[25]   COPER[13;]←ENGCAM[14;]
[26]   COPER[14;⍳RENG[18]]←0
[27]   COPER[14;RENG[18]+⍳RENG[19]]←PNEUX
[28]   COPER[15;]←RENG[13]×ENGEX[18;],CARBUR
[29]   COPER[16;]←+/[1]ENGCAM[16 17;]
[30]   COPER[17;]←+/[1]COPER[16 12 13 14 15;]
[31]   ⍝  LABOUR
[32]   Z←1+RENG[10]÷100
[33]   COPER[19;⍳Y←¯1↑⍴ENGEX]←Z×100×(+/[1](×/[1]ENGEX[19 20;]),[0.5]×/[1]
       ENGEX[21 22;])÷ENGEX[8;]
[34]   COPER[19;Y+⍳(⍴CAM)[2]]←Z×100×÷/[1]CAM[22 8;]
[35]   COPER[21;]←+/[1]COPER[11 19 17;]
[36]   COPER[23;]←ENGEX[23;],PROD
[37]   COPER[18;]←COPER[19;]×Z←RENG[15]×ENGCAM[8;]
[38]   COPER[20;]←COPER[21;]×Z
[39]   COPER[22;]←COPER[23;]×Z
[40]   ⍝ UNIT COST
[41]   COPER[24 25 27 28;]←COPER[11 17 19 21;]÷COPER[4⍴23;]
[42]   COPER[26;]←+/[1]COPER[24 25;]
     ∇
```

OUTPUT FONCTION :

```
    ∇ TABLEAU;I;F;N;NBM;Z;ZZ;R;RR
[1]   ⍝ RESULTS OUTPUT
[2]   PAGE[53;]←70↑(29⍴' '),'COST PER ',UNITEC[RENG[16];]
[3]   I←12 14 15 16 17
[4]   F←1 1 1 0 1 1 0 0 0 1 1 1 1 1 0 1 0 0 0 1 1 0 0 0 1 1 0 0 0 1 1 0
      0 0 0 1 1 0 1 0 1 0 1/20+⍳43
[5]   PAGE[(11+⍳6),F;⍳22]←TITRE
[6]   PAGE[50 51;1 2 3]←RFUNIT[2⍴RENG[16];]
[7]   NBM←1↑1↓⍴COPER
[8]   N←1
[9]   R1:Z←6⌊NBM
[10]  NBM←NBM-Z
[11]  PAGE[24 35 58 62;]←' '
[12]  PAGE[(11+⍳6),F;22+⍳48]←' '
[13]  PAGE[13;R←22+⍳8×Z]←,MACHC[COPER[2;RR←(6×N-1)+⍳Z];]
[14]  PAGE[I;R]←'BI8'ΔFMT COPER[1 3 4 5 6;RR]
[15]  PAGE[F;R]←'BF8.2'ΔFMT COPER[6+⍳22;RR]
[16]  PAGE[24;R]←(8×Z)⍴'   -----'
[17]  PAGE[35 58 62;]←PAGE[3⍴24;]
[18]  ⎕←PAGE
[19]  N←N+1
[20]  →(NBM≠0)/R1
    ∇
```

MISCELLANEOUS :

```
    ∇ A SI B
[1]   →(B×2)
[2]   0⍴∈A
    ∇
```

APPENDIX 3

PRESENTATION OF THE "SIMULATION" MODULE PROGRAM

1. Definition of simulation module program and its functions

The simulation module is stored in the computer's SIMULATION workspace and its main program is called SIMULA. The module incorporates many functions, which can be grouped as follows:

- -data input functions: enter the data from the input forms and execute any necessary corrections;
- -verification functions: present the storage data in the same format as on the forms;
- -simulation functions: control the activities of the machines being simulated;
- -result presentation functions: execute the appropriate calculations at the end of each simulation period and print out the results in table format;
- -service functions: called by one or more of the above functions for special operations, such as statistical compilation.

1.1 Definition of data input functions

DATA INPUT (LECTURE): Main function of this group; used to select the form whose data are to be entered or corrected.

ALFA: Enters or corrects the data from the Description of Chipping Operation and Logging Conditions form.

ALFA1: Enters or corrects the data from the Characteristics of the Simulation form.

CREA: Enters and corrects data presented in table format, i.e. the Data for Each Machine and Time Duration of Activities in Minutes forms.

1.2 Definition of verification functions

VERIF: Main function of this group; used to print out the storage data in the same format as on the forms; prints out the contents of the Description of the Chipping Operation and Logging Conditions form.

SIM2: Prints out the contents of the Characteristics of the Simulation form.

SIM3: Prints out the contents of the Data for Each Machine form.

SIM4: Prints out the contents of the Time Duration of Activities in Minutes form.

CORRIGE: Indicates the procedure for correcting erroneous data.

1.3 Definition of simulation functions

The simulation functions determine the logical and time sequence of machine activities during the simulation period.

DEBUT: Triggers the first activity of the machines at the start of each day simulated; determines the total duration of the simulation and controls production of the tables at the end of simulation by calling the presentation function group.

REAL: Time sequences the occurrence of the events and calls the logic function required by that event; controls the production of daily reports where required.

DEBAR: This logic function determines how the skidder disposes of its load at the chipping site.

CDEBAR: This logic function determines the skidder's next activity.

APPROCHE: This logic function controls the activities of a skidder assigned to rehandling wood from the chipper's storage pile.

BRDEBAR: This logic function determines the next activity of a skidder upon termination of breakdown.

ARCAM: This logic function determines whether a truck arriving at the chipping site is put on hold or loaded.

IDCAMAT: Identifies the truck that has been waiting the longest.

1.4 Definition of result presentation functions

RAPQ: Called when a daily report is produced for the day simulated; controls execution of the calcultations and printout of the tables.

RAPF: Called at the end of the simulation; controls execution of the calculations and printout of the tables for the period simulated.

CALPRECOU: Calculates the daily production costs for each machine.

OCCMAC: Sets up and prints the machine occupation tables.

VENTCOU: Sets up and prints the cost breakdown tables.

1.5 Definition of service functions

CALSTAT: Called during simulation; accumulates the data for the Statistics on Productivity table.

GENDUR: Generates the time duration of the activities during simulation; calls the appropriate functions for each type of distribution.

MOY: Generates the time duration of an activity based on its mean duration.

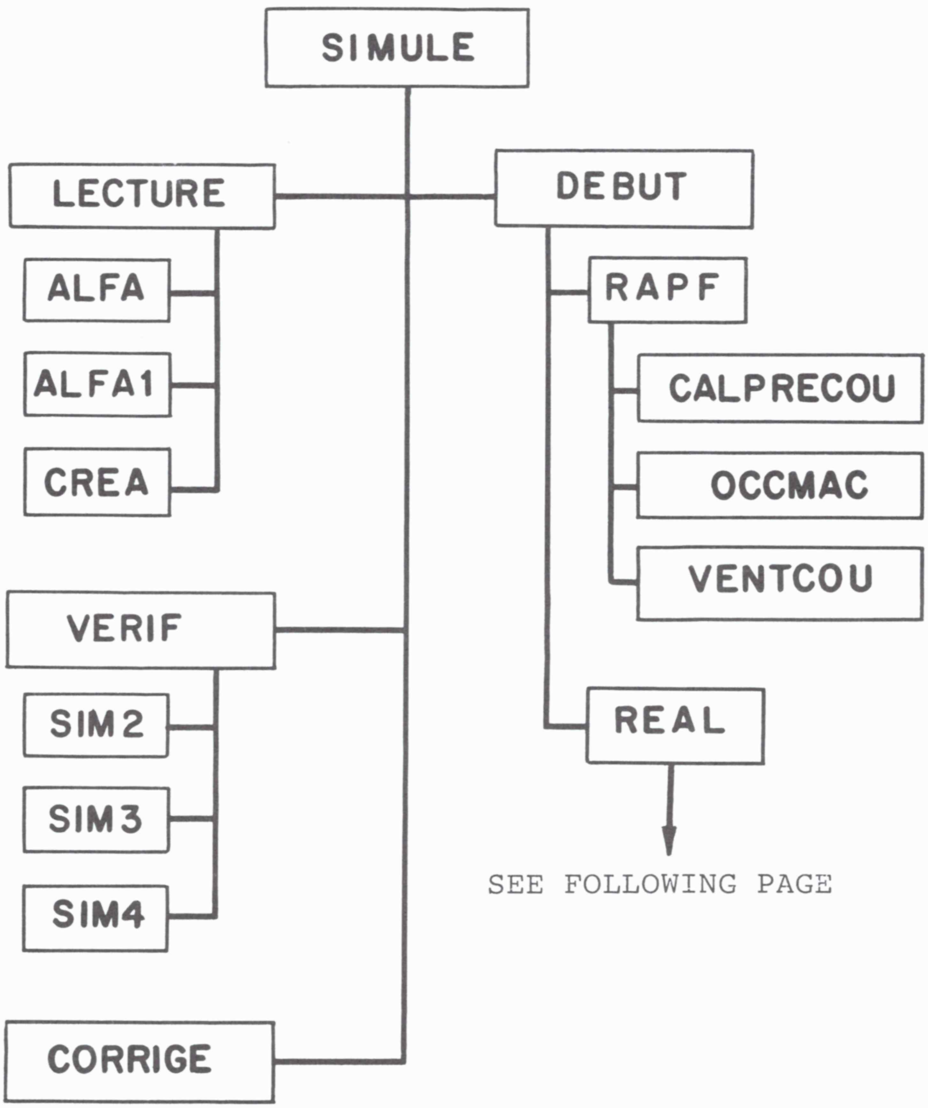
NRML: Generates the time duration of an activity based on normal distribution.

UNFR: Generates the time duration of an activity based on uniform distribution.

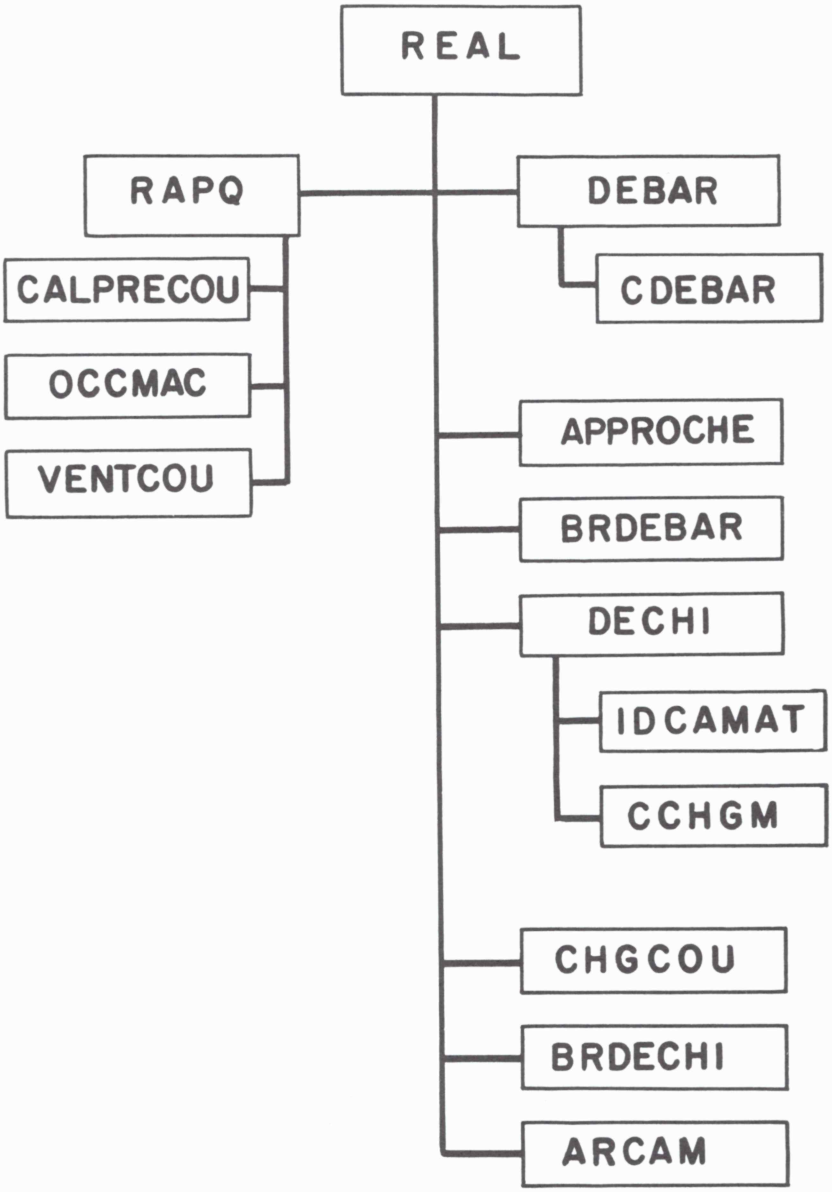
EXPON: Generates the time duration of an activity based on exponential distribution.

REPLACE: Updates the ACTIVITE matrix.

2- BLOCK DIAGRAM OF SIMULA PROGRAM



SEE FOLLOWING PAGE


REAL
RAPQ
CALPRECOU
OCCMAC
VENTCOU
DEBAR
CDEBAR
APPROCHE
BRDEBAR
DECHI
IDCAMAT
CCHGM
CHGCOU
BRDECHI
ARCAM

3- SIMULATION PROGRAM LISTING

MAIN PROGRAM FOR "SIMULA"

```
     ∇ SIMULE;A
[1]    ⍝  MAIN PROGRAM
[2]    ⍝  PROGRAM CONTROLING ALL STEPS OF SIMULATION
[3]    ⍝  (INPUT DATA, VERIFICATION, SIMULATION ITSELF, REPORT PRESENTATION)
[4]    '     THIS WORKSPACE SIMULATES A CHIPPING OPERATION.'
[5]    '     YOU MUST CHOOSE THE APPROPRIATE STEP'
[6]    ⍝
[7]    ⍝
[8]    ' '
[9]    RECO:2 1⍴' '
[10]   PHASE
[11]   '---->  ',NLF
[12]   →(4<A←∈⍞)/0
[13]   ∈(3↓,(MENU[A;]))
[14]   →RECO
     ∇
```

INPUT FONCTIONS :

```
    ∇ LECTURE;CHOIX
[1]   ⍝  INPUT DATA MAIN MODULE
[2]   CHOIX←5
[3]   ' '
[4]   '1- DESCRIPTION OF CHIPPING OPERATION AND LOGGING CONDITIONS.'
[5]   '2- CHARACTERISTICS OF THE SIMULATION.'
[6]   '3-  DATA FOR EACH MACHINE.'
[7]   '4- TIME DURATION OF ACTIVITIES IN MINUTES'
[8]   '5- END'
[9]   RECO:'---->    ',NLF
[10]  →((CHOIX←∊⍞)>5)/RECO
[11]  →(CHOIX=5)/0
[12]  →(CHOIX=1)/ALPHA
[13]  →(CHOIX=2)/FOR2
[14]  'HOW MANY LINES MUST BE ENTERED ? ',NLF
[15]  →(CHOIX=4)/DURA
[16]  ENTREE←((1↑∊⍞),12)CREA ENTREE
[17]  →1
[18]  DURA:
[19]  DURACT←((1↑∊⍞),8)CREA DURACT
[20]  →1
[21]  ALPHA:ALFA
[22]  →1
[23]  FOR2:ALFA1
[24]  →1
    ∇
```

```
∇ ALFA;NBMDB;C;NBMCA;DESCRP
  ⍝   MACHINES DATA INPUT
  'PROJECT NAME :',NLF
  X←⍞
  →(0=⍴X)/C1
  PROJET←25↑X
  C1:'SIMULATION: ',NLF
  X←⍞
  →(0=⍴X)/C2
  PASSE←55↑X
  C2:'DATE: ',NLF
  X←⍞
  →(0=⍴X)/C2
  DATE←15↑X
  RECO:CAS←1 QN'ENTER CODE FOR OPERATING MODE DESIRED'
  →(∨/CAS=1 2 3)/C00
  (2 6↑1 6⍴'CAS 1:'),¯1 30↓CAX[1;;]
  (3 6↑1 6⍴'CAS 2:'),0 30↓CAX[2;;]
  (3 6↑1 6⍴'CAS 3:'),0 30↓CAX[3;;]
  →RECO
  C00:NBMDB←1 QN'NUMBER OF SKIDDER TYPES: '
  →(NBMDB=0)/BRX
  C←0
  BR1:C←C+1
  'DESCRIPTION OF SKIDDER TYPE ';C
  DEBMOD←(NBMDB,50)↑DEBMOD
  ⎕←DEBMOD[C;]
  →(0=⍴DESCRP←⍞)/C01
  DEBMOD[C;]←50↑DESCRP
  C01:→(NBMDB>C)/BR1
  BRX:NBMCA←1 QN'NUMBER OF TRUCK TYPES: '
  NBMACH←1+NBMDB+NBMCA
  C←0
  BR2:C←C+1
  'DESCRIPTION OF TRUCK TYPE ';C
  CAMMOD←(NBMCA,50)↑CAMMOD
  ⎕←CAMMOD[C;]
  →(0=⍴DESCRP←⍞)/C02
  CAMMOD[C;]←50↑DESCRP
  C02:→(NBMCA>C)/BR2
  'DESCRIPTION OF THE CHIPPER: '
  ⎕←DECMOD
  →(0=⍴DESCRP←⍞)/C03
  DECMOD←50↑DESCRP
  C03:C←0
  BR3:C←C+1
  CX[C;47+⍳50]←50 QA CX[C;⍳47]
  →(8>C)/BR3
∇
```

```
     ∇ ALFA1
[1]    ⍝   SIMULATION DATA INPUT
[2]    NJAS←1 QN QUEST[1;]
[3]    QUEST[2;],NLF
[4]    IMPRQ←∊⍞
[5]    QUEST[3;],NLF
[6]    TRAJR←∊⍞
[7]    CODUN←1 QN QUEST[4;]
[8]    UNITE←,RFUNIT[CODUN;]
[9]    →(3≠CAS)/S2
[10]   BIOMAX←1 QN QUEST[5;]
[11]   BIOAP←1 QN QUEST[6;]
[12]   BIOD←1 QN QUEST[7;]
[13]   BIOR←1 QN QUEST[8;]
[14]   →TOUS
[15]   S2:→(1=CAS)/S1
[16]   BIOMAX←1 QN QUEST[5;]
[17]   BIOAP←BIOR←0
[18]   BIOD←1 QN QUEST[7;]
[19]   →TOUS
[20]   S1:BIOMAX←BIOD←10*5
[21]   BIOAP←BIOR←0
[22]   TOUS:INTCOUN←1 QN QUEST[9;]
[23]   INTCOU←INTCOUN
[24]   JOUR←1 QN QUEST[10;]
[25]   PRIME←1 QN QUEST[11;]
[26]   BENMARG←1 QN QUEST[12;]
     ∇
```

```
    ∇ R←A CREA B;RO;C;DR;D
[1]   ⍝   SUB-MODULE FOR DATA INPUTS ON TABLE FORM
[2]   ⍝
[3]   B←A↑B
[4]   →(12≠¯1↑A)/CON
[5]   B←0 1↓B
[6]   CON:RO←1↑⍴B
[7]   '(P)REVIOUS    (S)TEP    (T)O END'
[8]   'LINE      DATA'
[9]   C←0
[10]  BR:C←C+1
[11]  NBR:'C←1'SI(C≤0)
[12]  'C←RO'SI(C>RO)
[13]  DR←C
[14]  (,('I3'∆FMT C)),'        ';,B[C;]
[15]  (,('I3'∆FMT C)),'        ',NLF
[16]  'C←C-2'SI('P'=1↑D←⍞)
[17]  'C←C-1'SI~(∨/(1↑D)='PST⍴⍳.¯ 1234567890')
[18]  'C←C+1'SI('S'=1↑D)
[19]  →(DR≠C)/BR
[20]  →('T'=1↑D)/FIN
[21]  →(~(∧/D∈'.¯ ⍳⍴1234567890'))/NBR
[22]  →(0=⍴D)/CT
[23]  B[C;]←(¯1↑⍴B)↑(∊D)
[24]  CT:→(C<RO)/BR
[25]  FIN:B←B[⍋B[;2];]
[26]  B←B[⍋B[;1];]
[27]  →(8=¯1↑A)/NOREF
[28]  B←(((1↑A),1)⍴⍳(1↑A)),B
[29]  NOREF:R←B
    ∇
```

VERIFICATION FONCTIONS :

```
    ∇ VERIF;RESTE
      ⍝  PRINTING OF INPUT DATA FOR VERIFICATION
      0⍴⍞,⍞←'SET PAPER ON LAST LINE AND PRESS RETURN'
      2 1⍴' '
      SIM1S
      2 1⍴' '
      '      DESCRIPTION OF CHIPPING OPERATION AND LOGGING CONDITIONS'
      '      --------------------------------------------------------'
      2 1⍴' '
      0 30↓3 132⍴CAX[CAS;;]
      2 1⍴' '
      '         MACHINES'
      '         --------'
      ' '
      →(0=NBMDB)/S1
      '         SKIDDERS'
      ⎕←'X15,⎕  TYPE: ⎕,I2,X10,50A1'ΔFMT(⍳(1↑⍴DEBMOD);DEBMOD)
      ' '
      S1:'            CHIPPER'
      (15⍴' '),'  TYPE:    ',(10⍴' '),DECMOD
      ' '
      '           TRUCKS'
      ⎕←'X15,⎕  TYPE: ⎕,I2,X10,50A1'ΔFMT(⍳(1↑⍴CAMMOD);CAMMOD)
      RESTE←|13-(1↑⍴DEBMOD)+(1↑⍴CAMMOD)
      (RESTE,1)⍴' '
      'DESCRIPTION OF STAND AND LOGGING SITE:'
      '--------------------------------------'
      0 1 1 1 1 0 1 1 1 0 1\[1](8 5⍴' '),(8 102↑CX)
      14 1⍴' '
      SIM2
      SIM3
      SIM4
    ∇
```

```
    ∇ SIM2
      ⍝  CHARACTERISTICS OF SIMULATION OUTPUT
      7 1⍴' '
      'CHARACTERISTICS OF THE SIMULATION'
      '----------------------------------'
      4 1⍴' '
      'DAYS OF SIMULATION  (NJAS)                                         :'
      ⍕NJAS
      'PRESENTATION OF DAILY REPORT FOR DAYS  (IMPRQ)                     :'
      ⍕IMPRQ
      'TRACE OF ACTIVITIES PRESENTED FOR DAYS  (TRAJR)                    :'
      ⍕TRAJR
      ' '
      'BIOMASS MEASUREMENT UNIT   (ACCORDING TO SPECIFIED CODE)           :'
      ⍕UNITE
      ' '
      'MAXIMUM AMOUNT OF WOOD THAT COULD BE STORED AT CHIPPER (BIOMAX):'
      ⍕BIOMAX
      ' '
      'WOOD IS REHANDLED FROM STORAGE PILES WHEN AMOUNT OF WOOD'
      'AT CHIPPER IS LESS THAN  (BIOAP)                                   :'
      ⍕BIOAP
      ' '
      'AMOUNT OF WOOD STORED CLOSE TO CHIPPER SITE AT BEGINNING'
      'OF SIMULATION  (BIOD)                                              :'
      ⍕BIOD
      ' '
      'AMOUNT OF WOOD STORED AT CHIPPER AT BEGINNING '
      'OF SIMULATION  (BIOR)                                              :'
      ⍕BIOR
      ' '
      'TRUCK LOADS CHIPPED WITH SAME SET OF KNIVES  (INTCOUN)             :'
      ⍕INTCOUN
      ' '
      'WORKING MINUTES PER SHIFT  (JOUR)                                  :'
      ⍕JOUR
      ' '
      'OVERTIME PREMIUM AS A o/o OF THE REGULAR RATE (PRIME)              :'
      ⍕PRIME
      ' '
      'FRINGE BENEFITS, AS A o/o OF SALARIES  (BENMARG)                   :'
      ⍕BENMARG
      8 1⍴' '
      'COMMENTS'
      '--------'
      17 1⍴' '.
    ∇
```

```
    ∇ SIM3;AS;ASX
[1]   ⍝  PRINTOUT OF INPUT DATA FOR EACH MACHINE
[2]   5 1⍴' '
[3]   AS←0 1↓ENTREE
[4]   FCX←MACH[AS[;1];]
[5]   ASX←'X4,13A1,I8,I13,I12,BF9.2,I10,BF11.2,BF10.2,2BF9.2,BF14.2'
      ⍕FMT(FCX;(0 1↓AS))
[6]   XTDONNE[11;56 57 58]←UNITE
[7]   XTDONNE
[8]   ' '
[9]   ASX
[10]  2 1⍴' '
[11]  NOTABENE
[12]  2 1⍴' '
[13]  XTDONX[5;46 47 48 79 80 81 112 113 114]←9⍴UNITE
[14]  XTDONX[9;46 47 48]←UNITE
[15]  XTDONX[12;46 47 48 79 80 81]←6⍴UNITE
[16]  XTDONX
[17]  ((66-((1↑⍴XTDONNE)+(1↑⍴XTDONX)+NBMACH+5)),1)⍴' '
    ∇
```

```
    ∇ SIM4;RO;FMT;X1;X2;X3;X4;X5;C
[1]   ⍝   PRINTOUT OF TIME DURATION OF ACTIVITIES TABLE
[2]   RO←1↑⍴DURACT
[3]   4 1⍴' '
[4]   XTDUX
[5]   C←0
[6]   BR:C←C+1
[7]   X1←1 7⍴(MACH[DURACT[C;1];])
[8]   X2←DURACT[C;2]
[9]   X3←1 57⍴MATDUX[DURACT[C;1];DURACT[C;3];]
[10]  X4←1 4⍴DISTRIB[DURACT[C;4];]
[11]  X5←1 4⍴DURACT[C;5 6 7 8]
[12]  FMT←'X3,7A1,X4,I2,X8,57A1,X7,4A1,X5,4BF7.1'
[13]  FMT ⍕FMT(X1;X2;X3;X4;X5)
[14]  →(C<RO)/BR
[15]  4 1⍴' '
[16]  XTSPARAM
[17]  ((66-(1↑⍴XTDUX)+(1↑⍴XTSPARAM)+RO+8),1)⍴' '
    ∇
```

```
    ∇ CORRIGE
[1]    ⍝  INSTRUCTIONS ON HOW TO MAKE CORRECTIONS
[2]    '   TO MAKE CORRECTIONS , CALL THE "DATA INPUTS" MODULE'
[3]    '   AND MAKE THE APPROPRIATE CORRECTIONS'
[4]    ' '
[5]    'NOTE:  ON THE "CHARACTERISTICS OF THE SIMULATION" FORM'
[6]    '       YOU MUST SPECIFY DIRECTLY (LIKE A←10) THE VALUE ON THE VAR
       IABLE'
    ∇
```

SIMULATION FONCTIONS :

```
    ∇ DEBUT;Y;I;D
      ⍝  START SIMULATION AT THE BEGINNING OF EACH DAY
      0⍴⎕,⍞←'SET PAPER TO LAST LINE AND PRESS RETURN'
      NBL←1↑⍴ENTREE
      STAT←6 5⍴0
      STAT[;4]←10000
      ACT←(NBL,20)⍴0
      CUMULE←(NBL,14)⍴0
      ACT[;1 2 3]←CUMULE[;1 2 3]←ENTREE[;1 2 3]
      JR←0
      NOUVELLEJOURNEE:
      JR←JR+1
      →(~(TRACE←(∨/(JR∊TRAJR))))/S1
      2 1⍴' '
      '                                   TRACE OF DAY ';JR
      S1:DECATB←DECATC←DEBAT←CAMAT←APR←0
      ACT[;3+⍳17]←0
      ACT[;6 7 8 9]←ENTREE[;3+⍳4]
      ACT[;18]←15+(?NBL⍴1500)÷100
      ACT[;5]←+/ACT[;6 18]
      ACT[((ACT[;2]=1)/⍳NBL);4]←8
      ACT[D←((ACT[;2]=2)/⍳NBL);4]←5
      Y←,(ACT[;2]=3)/⍳NBL
      I←1
      BOUC:ACT[Y[I];9]←JOUR+ACT[D;6]-ENTREE[Y[I];7]
      ACT[Y[I];5 11]←ACT[Y[I];5 11]+3 GENDUR ACT[Y[I];]
      →((⍴Y)≥I←I+1)/BOUC
      ACT[Y;4]←7
      REAL
      →(JR<NJAS)/NOUVELLEJOURNEE
      RAPF
    ∇
```

```
    ∇ REAL;X;LPA;OPE;OPERA
[1]   ⍝  CONTROL MODULE FOR EXECUTION OF ACTIVITIES
[2]   NBL←1↑⍴ACT
[3]   BOUC:HEURE←⌊/(ACT[((ACT[;5]≥0)/⍳NBL);5])
[4]   →(HEURE=6000)/FIN
[5]   LPA←,((ACT[;5]=HEURE)/⍳NBL)
[6]   →(1=X←+/((OPE←,(ACT[LPA;4]))=4))/ERR2
[7]   →(X>2)/ERR3
[8]   →(X=0)/UNE
[9]   LPA←(OPE=4)/LPA
[10]  OPE←4
[11]  →(ACT[LPA[1];2]=3)/CAMDEC
[12]  VTD←ACT[LPA[1];]
[13]  VTC←ACT[LPA[2];]
[14]  →GEN
[15]  CAMDEC:VTC←ACT[LPA[1];]
[16]  VTD←ACT[LPA[2];]
[17]  →GEN
[18]  UNE:VTS←ACT[LPA[1];]
[19]  GEN:HEURE←1↑HEURE
[20]  →(~TRACE)/S1
[21]  ' TIME: ';HEURE
[22]  S1:OPERA←,FCT[1↑OPE;]
[23]  →(~TRACE)/S2
[24]  '    ','ACTIVITY: ';OPERA
[25]  S2:⍎OPERA
[26]  →BOUC
[27]  FIN:→(~TRACE)/S3
[28]  3 1⍴' '
[29]  0⍴⍞,⍞←'SET PAPER TO LAST LINE AND PRESS RETURN'
[30]  S3:RAPQ
[31]  →0
[32]  ERR2:→AT;'ONLY ONE CHIPPING ACTIVITY DETECTED; STOP PROCESSING'
[33]  ERR3:→AT;'MORE THAN TWO MACHINES INVOLVED DURING CHIPPING; STOP PR
      OCESSING'
[34]  AT:⍎')SI CLEA'
[35]  →0
    ∇
```

```
    ∇ DEBAR
[1]   ⍝   SIMULATION OF SKIDDING -  DETERMINATION OF BIOMASS STORAGE LOC
      ATION
[2]   ⍝
[3]   →(BIOD<BIOMAX)/DECHAR
[4]   →(CAS=3)/RESER
[5]   →((+/(((ACT[;2]=3)/[1]ACT[;5])≠6000))≠0)/PASFJ
[6]   BIOD←BIOD+VTS[8]
[7]   VTS[4]←VTS[5]
[8]   VTS[13]←VTS[13]+VTS[8]
[9]   VTS[5]←6000
[10]  →0;REPLACE VTS
[11]  PASFJ:VTS[4]←9
[12]  VTS[5]←-VTS[5]
[13]  DEBAT←1
[14]  →0;REPLACE VTS
[15]  RESER:BIOR←BIOR+VTS[8]
[16]  VTS[14]←VTS[14]+VTS[8]
[17]  →TBRIS
[18]  DECHAR:BIOD←BIOD+VTS[8]
[19]  VTS[13]←VTS[13]+VTS[8]
[20]  →(DECATB=0)/TBRIS
[21]  DECATB←0
[22]  VTD←,((ACT[;2]=2)/[1]ACT)
[23]  VTD[16]←VTD[16]+WAIT←HEURE+VTD[5]
[24]  VTD[5]←HEURE
[25]  3 CALSTAT WAIT
[26]  VTD[4]←4
[27]  REPLACE VTD
[28]  VTC←,(ACT[;4]=10)/[1]ACT
[29]  VTC[17]←VTC[17]+WAIT←(HEURE+VTC[5])
[30]  VTC[4]←4
[31]  VTC[5]←HEURE
[32]  REPLACE VTC
[33]  TBRIS:→((?1000)>VTS[7])/PASBRIS
[34]  VTS[5 18]←VTS[5 18]+4 GENDUR VTS
[35]  VTS[4]←3
[36]  →0;REPLACE VTS
[37]  PASBRIS:CDEBAR
    ∇
```

```
    ∇ CDEBAR
[1]   ⍝   SIMULATION OF SKIDDING OPERATION
[2]   ⍝
[3]   →(HEURE≥(JOUR+VTS[6]))/FINJOUR
[4]   TSUP:→((BIOD-VTS[8])≥BIOAP)/CTDB
[5]   →(APR=1)/CTDB
[6]   →(VTS[9]≠1)/CTDB
[7]   →(~∨/(ACT[;4]=4),ACT[;4]=10)/CTDB
[8]   →(BIOR≤VTS[8])/CTDB
[9]   APR←1
[10]  BIOR←BIOR-VTS[8]
[11]  VTS[4]←2
[12]  VTS[5 12]←VTS[5 12]+2 GENDUR VTS
[13]  VTS[15]←VTS[15]+VTS[8]
[14]  →TERM
[15]  CTDB:VTS[4]←1
[16]  VTS[5 10]←VTS[5 10]+1 GENDUR VTS
[17]  →TERM
[18]  FINJOUR:→(∨/6000≠((ACT[;2]≠1)/[1]ACT[;5]))/TSUP
[19]  VTS[4]←VTS[5]
[20]  VTS[5]←6000
[21]  TERM:REPLACE VTS
    ∇
```

```
    ∇ APPROCHE
      ⍝  SIMULATION OF ACTIVITIES FOR SKIDDER AFFECTED TO THE
      ⍝  REHANDLING OF BIOMASS STORED AT CHIPPER SITE
      ⍝
      →(BIOD<BIOMAX)/DECHAR
      BIOD←BIOD+VTS[8]
      APR←0
      CDEBAR
      →TERM
      PASFJ:VTS[4]←9
      VTS[5]←-VTS[5]
      DEBAT←1
      →TERM
      DECHAR:BIOD←BIOD+VTS[8]
      →(DECATB=0)/TBRIS
      DECATB←0
      VTD←,((ACT[;2]=2)/[1]ACT)
      VTD[16]←VTD[16]+WAIT←(HEURE+VTD[5])
      VTD[5]←HEURE
      3 CALSTAT WAIT
      VTD[4]←4
      REPLACE VTD
      VTC←,(ACT[;4]=10)/[1]ACT
      VTC[17]←VTC[17]+WAIT←(HEURE+VTC[5])
      VTC[5]←HEURE
      VTC[4]←4
      REPLACE VTC
      TBRIS:→((?1000)>VTS[7])/PASBRIS
      VTS[5 18]←VTS[5 18]+4 GENDUR VTS
      VTS[4]←3
      APR←0
      →TERM
      PASBRIS:→(~∨/ACT[;4]=4)/CESAPR
      →(BIOR<VTS[8])/CESAPR
      BIOR←BIOR-VTS[8]
      VTS[5 12]←VTS[5 12]+2 GENDUR VTS
      VTS[15]←VTS[15]+VTS[8]
      →TERM
      CESAPR:APR←0
      CDEBAR
      TERM:REPLACE VTS
      →0
      BREAK:'STOP PROCESS'
      ∈')SI CLEAR'
    ∇

    ∇ R←IDCAMAT;BIN;VTC;X
      ⍝  SEARCHING AND IDENTIFICATION OF TRUCK WAITING
      →((+/BIN←(ACT[;4]=12))>1)/PLUS
      VTC←,(BIN/[1]ACT)
      CAMAT←0
      →BR2
      PLUS:X←⌈/ACT[BIN/⍳NBL;5]
      VTC←ACT[1↑((ACT[;5]=X)/⍳NBL);]
      BR2:R←VTC
    ∇

    ∇ BRDEBAR
      ⍝   SIMULATION OF SKIDDER'S BREAKDOWN TERMINATION
      CDEBAR
    ∇
```

```
     ∇ DECHI;BIN;NBD;MATDEB;C
[1]    ⍝  SIMULATION OF CHIPPING OPERATION AND TRUCK LOADING
[2]    →(VCAM>0)/CHARGE
[3]    INTCOU←INTCOU-1
[4]    →(VTC[5]≥VTC[9])/DURFU
[5]    →((?1000)>VTC[7])/DURVOY
[6]    VTC[5 18]←VTC[5 18]+4 GENDUR VTC
[7]    →(VTC[5]≥VTC[9])/DURFU
[8]    DURVOY:VTC[5 11]←VTC[5 11]+1 GENDUR VTC
[9]    VTC[14]←VTC[14]+VTC[8]
[10]   VTC[4]←7
[11]   →TBDEC
[12]   DURFU:VTC[4 11]←VTC[5 11]+2 GENDUR VTC
[13]   VTC[14]←VTC[14]+VTC[8]
[14]   VTC[5]←6000
[15]   TBDEC:REPLACE VTC
[16]   →((?1000)≤VTD[7])/BRISD
[17]   →(INTCOU≤0)/COUTEAU
[18]   →(CAMAT=1)/IDCAM
[19]   DECATC←1
[20]   VTD[5]←-VTD[5]
[21]   VTD[4]←11
[22]   →TFJOUR
[23]   BRISD:VTD[5 18]←VTD[5 18]+4 GENDUR VTD
[24]   VTD[4]←6
[25]   →TFJOUR
[26]   COUTEAU:VTD[5 11]←VTD[5 11]+2 GENDUR VTD
[27]   VTD[14]←VTD[14]+1
[28]   INTCOU←INTCOUN
[29]   VTD[4]←5
[30]   →TFJOUR
[31]   IDCAM:VTC←IDCAMAT
[32]   VTC[16]←VTC[16]+WAIT←(HEURE+VTC[5])
[33]   VTC[5]←HEURE
[34]   VTC[4]←4
[35]   1 CALSTAT WAIT
[36]   VCAM←VTC[8]
[37]   CHARGE:CCHGM
[38]   →0
[39]   TFJOUR:→((+/(((ACT[;2]=3)/[1]ACT[;5])≠6000))≠0)/PASFJ
[40]   VTD[4]←|VTD[5]
[41]   VTD[5]←6000
[42]   →(DEBAT=0)/PASFJ
[43]   NBD←+/BIN←ACT[;4]=9
[44]   MATDEB←BIN/[1]ACT
[45]   C←0
[46]   BR:C←C+1
[47]   MATDEB[C;16]←MATDEB[C;16]+WAIT←HEURE+MATDEB[C;5]
[48]   4 CALSTAT WAIT
[49]   →(C<NBD)/BR
[50]   MATDEB[;5]←6000
[51]   ACT[BIN/⍳NBL;]←MATDEB
[52]   PASFJ:REPLACE VTD
     ∇
```

```
     ∇ CHGCOU
[1]    ⍝   SIMULATION OF CHANGES OF CHIPPER'S KNIFES
[2]    VTD←VTS
[3]    →(CAMAT=1)/IDCAM
[4]    VTD[5]←-VTD[5]
[5]    VTD[4]←11
[6]    DECATC←1
[7]    REPLACE VTD
[8]    →0
[9]    IDCAM:VTC←,IDCAMAT
[10]   VTC[16]←VTC[16]+WAIT←HEURE+VTC[5]
[11]   VTC[5]←HEURE
[12]   VTD[4]←VTC[4]←4
[13]   1 CALSTAT WAIT
[14]   VCAM←VTC[8]
[15]   CCHGM
     ∇

     ∇ BRDECHI
[1]    ⍝   SIMULATION OF CHIPPER'S BREAKDOWN TERMINATION
[2]    CHGCOU
     ∇

     ∇ ARCAM
[1]    ⍝   SIMULATION OF TRUCK ARRIVAL AT CHIPPER SITE
[2]    VTC←VTS
[3]    →(DECATC=0)/CAT
[4]    VTD←,((ACT[;2]=2)/[1]ACT)
[5]    VTD[17]←VTD[17]+WAIT←(HEURE+VTD[5])
[6]    2 CALSTAT WAIT
[7]    VTD[4]←VTC[4]←4
[8]    VTD[5]←HEURE
[9]    DECATC←0
[10]   VCAM←VTC[8]
[11]   CCHGM
[12]   →0
[13]   CAT:VTC[5]←-VTC[5]
[14]   VTC[4]←12
[15]   CAMAT←1
[16]   REPLACE VTC
     ∇
```

```
    ∇ R←IDCAMAT;BIN;VTC;X
      ⍝  SEARCHING AND IDENTIFICATION OF TRUCK WAITING
      →((+/BIN←(ACT[;4]=12))>1)/PLUS
      VTC←,(BIN/[1]ACT)
      CAMAT←0
      →BR2
      PLUS:X←⌈/ACT[BIN/⍳NBL;5]
      VTC←ACT[1↑((ACT[;5]=X)/⍳NBL);]
      BR2:R←VTC
    ∇
```

OUTPUT FONCTIONS :

```
    ∇ RAPQ;DUREX;Y;X;YY;NTEMP
[1]   ⍝  CONTROL AND PRINTING OF DAILY REPORTS
[2]   ⍝
[3]   →(∨/ACT[;5]<0)/BREAK
[4]   DUREX←JOUR+ACT[;6]
[5]   Y←DUREX-ACT[;4]
[6]   YY←(10>|Y)/⍳NBL
[7]   →(0=⍴,YY)/CONT
[8]   ACT[YY;10]←ACT[YY;10]+Y[YY]
[9]   ACT[YY;4]←DUREX[YY]
[10]  CONT:ACT[;20]←30×⌈((ACT[;4]-DUREX)×(ACT[;4]>DUREX))÷30
[11]  ACT[;19]←(DUREX-ACT[;4])×(ACT[;4]<DUREX)
[12]  X←,(ACT[;2]=1)/⍳NBL
[13]  →(0=⍴X)/PDB
[14]  YY←ACT[X;13 14]÷⍉(2,(⍴X))⍴+/ACT[X;13 14]
[15]  ACT[X;10 11]←ACT[X;10 10]×YY
[16]  PDB:ACT[;Y]←ACT[;Y←10 11 12 16 17 18 19 20]÷60
[17]  CUMULE[;3+⍳11]←CUMULE[;3+⍳11]+ACT[;9+⍳11]
[18]  5 CALSTAT X←ACT[((ACT[;2]=2)/⍳NBL);13]
[19]  NTEMP←ACT[;(⍳3),(9+⍳11)]
[20]  CALPRECOU NTEMP
[21]  6 CALSTAT(+/MPC[;4])÷X
[22]  →(~(JR∊IMPRQ))/FIN
[23]  3 1⍴' '
[24]  SIM1
[25]  ' '
[26]  (40⍴' '),'OCCUPATION OF MACHINES IN HOURS'
[27]  (40⍴' '),'-------------------------------'
[28]  ' '
[29]  (40⍴' '),'        TABLE FOR DAY ';JR
[30]  OCCMAC NTEMP
[31]  2 1⍴' '
[32]  3 1⍴' '
[33]  SIM1
[34]  ' '
[35]  (45⍴' '),'BREAKDOWN OF COSTS'
[36]  (45⍴' '),'------------------'
[37]  ' '
[38]  (45⍴' '),'  TABLE FOR DAY ';JR
[39]  VENTCOU NTEMP
[40]  FIN:→0
[41]  BREAK:'***** SOME MACHINES ARE STILL WAITING AFTER DAY ';JR
[42]  ' STOP PROCESSING'
[43]  ∊')SI CLEAR'
    ∇
```

```
∇ RAPP;ALPSTAT;Z;MTEMP
  ⍝  CONTROL AND PRINTING OF REPORTS AT END OF SIMULATION
  ⍝
  MTEMP←CUMULE[;⍳3],CUMULE[;3+⍳11]÷NJAS
  CALPRECOU MTEMP
  3 1⍴' '
  SIM1
  ' '
  (40⍴' '),'OCCUPATION OF MACHINES IN HOURS     '
  (40⍴' '),'-------------------------------     '
  ' '
  (34⍴' '),' AVERAGE VALUES PER DAY FOR ';NJAS;' DAYS'
  OCCMAC MTEMP
  3 1⍴' '
  SIM1
  ' '
  (45⍴' '),'BREAKDOWN OF COSTS    '
  (45⍴' '),'------------------    '
  ' '
  (33⍴' '),' AVERAGE VALUES PER DAY FOR ';NJAS;' DAYS'
  VENTCOU MTEMP
  STAT[;2]←÷/STAT[;2 1]
  STAT[;3]←((STAT[;3]-×/STAT[;2 2 1])÷STAT[;1]-1)*0.5
  Z←(STAT[;1]≤1)/⍳6
  →(0=⍴,Z)/OK
  STAT[Z;2 3 4]←0
  OK:3 1⍴' '
  SIM1
  ' '
  (40⍴' '),'STATISTICS ON PRODUCTIVITY'
  (40⍴' '),'--------------------------'
  ' '
  (40⍴' '),'NUMBER OF DAYS SIMULATED: ';NJAS
  2 1⍴' '
  XTSTAT
  XTSTAT2[5;27+⍳15]←QUANTITE[CODUN;]
  ALPSTAT←'BI9,4BF10.2'ΔFMT STAT
  ⎕←XTSTAT2,ALPSTAT
  ((51-1↑⍴XTSTAT),1)⍴' '
∇
```

```
    ∇ CALPRECOU A;TREG;TSUP;TBASE
[1]   ⍝   DAILY COSTS PRELIMINARY CALCULATIONS
[2]   MPC←(NBL,4)⍴0
[3]   TBASE←ENTREE[;12]
[4]   TREG←(JOUR÷60)×TBASE×1+BENMARG÷100
[5]   TSUP←A[;14]×TBASE×1+PRIME÷100
[6]   MPC[;1]←TREG+TSUP
[7]   MPC[;2]←ENTREE[;8]
[8]   MPC[;3]←+/(A[;4 5 6])×ENTREE[;9 10 11]
[9]   MPC[;4]←+/MPC[;1 2 3]
    ∇
```

```
    ∇ OCCMAC A;ALPMMX;C;L;MMX;NUM;MNUM;PNUM;PAG
[1]   ⍝ COMPUTE AND PRINT "OCCUPATION OF MACHINES" REPORT
[2]   PAG←NBL+7
[3]   MMX←(NBL,18)⍴0
[4]   MMX[;(⍳10),15,16,17]←A[;(⍳6),(9+⍳4),(6+⍳3)]
[5]   MMX[;11]←+/MMX[;4 5 6 10 7 8 9]
[6]   MMX[;12]←A[;14]+JOUR÷60
[7]   MMX[;13]←100×(+/A[;4 5 6])÷MMX[;11]
[8]   MMX[;14]←100×1-÷/MMX[;9 11]
[9]   MMX[;18]←MPC[;4]
[10]  XTOM[6;102 103 104 110 111 112 118 119 120]←9⍴UNITE
[11]  PAG←PAG+1↑⍴XTOM
[12]  XTOM
[13]  C←0
[14]  BR:C←C+1
[15]  →(0=+/MMX[;2]=C)/S1
[16]  MACH[C;]
[17]  ⎕←'3BI4,BF10.2,2BF8.2,4BF7.2,BF8.2,BF7.1,2BI7,BI9,2BI8,BF9.2'ΔFMT
      NUM←((MMX[;2]=C)/[1]MMX)
[18]  XTTOM
[19]  PAG←PAG+2
[20]  MNUM←(+/[1]NUM)÷1↑⍴NUM
[21]  MNUM[13 14]←0
[22]  MNUM←3↓MNUM
[23]  →(C=2)/PC
[24]  ⎕←'12A1,BF10.2,2BF8.2,4BF7.2,BF8.2,BF7.1,2BI7,BI9,2BI8,BF9.2'ΔFMT(
      (1 12⍴'AVERAGE     ');(1 15⍴MNUM))
[25]  PAG←PAG+1
[26]  PC:PNUM←100×(MNUM÷MNUM[8])
[27]  PNUM[10]←+/PNUM[1 2 3]
[28]  PNUM[11]←+/PNUM[10 4 5 7]
[29]  PNUM[9 12 13 14 15]←0
[30]  ⎕←'12A1,BI10,2BI8,4BI7,BI8,3BI7,BI9,2BI8,BI9'ΔFMT((1 12⍴'PERCENTAG
      E  ');(1 15⍴PNUM))
[31]  PAG←PAG+1
[32]  S1:2 1⍴' '
[33]  PAG←PAG+2
[34]  →(C<3)/BR
[35]  XTCSE
[36]  ((64-(PAG+1↑⍴XTCSE)),1)⍴' '
    ∇
```

```
    ∇ VENTCOU A;MX;MXT;MXT2;Z;C;NUM;BIN;NUM2;MVOL;PAG
[1]    ⍝  REPORT "BREAKDOWN OF COSTS"
[2]    ⍝
[3]    PAG←NBL+7
[4]    MX←(NBL,19)⍴0
[5]    MX[;⍳7]←A[;⍳3],MPC
[6]    MXT←(⍉(3,NBL)⍴(MX[;4]÷+/A[;4 5 6]))×A[;4 5 6]
[7]    MVOL←A[;7 8 9]+10*¯10
[8]    MX[;8 11 14]←MXT÷MVOL
[9]    MXT2←(((⍉(3,NBL)⍴(MX[;5]÷+/A[;4 5 6]))×A[;4 5 6])+(A[;4 5 6])×
       ENTREE[;9 10 11])
[10]   MX[;9 12 15]←MXT2÷MVOL
[11]   MX[;10]←+/MX[;8 9]
[12]   MX[;13]←+/MX[;11 12]
[13]   MX[;16]←+/MX[;14 15]
[14]   Z←A[(A[;2]=2)/⍳NBL;7]
[15]   MX[;17 19]←MX[;4 7]÷Z
[16]   MX[;18]←(+/MX[;5 6])÷Z
[17]   XTVENCOU[2;74+⍳11]←TABUNITE[CODUN;]
[18]   XTVENCOU[3;112+⍳11]←TABUNITE[CODUN;]
[19]   XTVENCOU
[20]   PAG←PAG+(1↑⍴XTVENCOU)
[21]   C←0
[22]   BR:C←C+1
[23]   →(0=+/MX[;2]=C)/S1
[24]   MACH[C;]
[25]   NUM←(BIN←(MX[;2]=C))/[1]MX
[26]   PAG←PAG+2
[27]   →(C≠2)/AU
[28]   ⎕←'I3,2I4,3BI7,BI8,2BF7.2,BF8.2,2BF7.2,BF8.2,2BF7.2,BF8.2,2BF7.2,B
       F8.2'ΔFMT NUM
[29]   →S1
[30]   AU:⎕←'I3,2I4,3BI7,BI8,2BF7.2,BF8.2,2BF7.2,BF8.2,2BF7.2,BF8.2,'
       ΔFMT NUM[;⍳16]
[31]   XTTVC
[32]   ⎕←'11A1,3BI7 ,BI8 ,66X1,2BF7.2,BF8.2'ΔFMT((1 11⍴' SUB-TOTAL:');(1
       7⍴(+/[1]NUM[;4 5 6 7 17 18 19])))
[33]   PAG←PAG+1
[34]   NUM2←9⍴0
[35]   NUM2[1 4 7]←(+/[1](BIN/[1]MXT))÷(+/[1](BIN/[1]MVOL))
[36]   NUM2[2 5 8]←(+/[1](BIN/[1]MXT2))÷(+/[1](BIN/[1]MVOL))
[37]   NUM2[3 6 9]←(+/NUM2[1 2]),(+/NUM2[4 5]),(+/NUM2[7 8])
[38]   ⎕←'11A1,X29,2BF7.2,BF8.2,2BF7.2,BF8.2,2BF7.2,BF8.2'ΔFMT((1 11⍴'AVE
       RAGE:    ');(1 9⍴NUM2))
[39]   PAG←PAG+1
[40]   S1:2 1⍴' '
[41]   PAG←PAG+2
[42]   →(C<3)/BR
[43]   XTTVC
[44]   ⎕←'11A1,3BI7 ,BI8 ,66X1,2BF7.2,BF8.2'ΔFMT((1 11⍴'      TOTAL');(1
       7⍴(+/[1]MX[;4 5 6 7 17 18 19])))
[45]   ((63-PAG),1)⍴' '
    ∇
```

MICELLANEOUS FONCTIONS :

```
    ∇ A CALSTAT B
      ⍝   CALCULATION OF STATISTICS
      STAT[A;4]←⌊/B,STAT[A;4]
      STAT[A;5]←⌈/B,STAT[A;5]
      STAT[A;⍳3]←STAT[A;⍳3]+(1,B,(B*2))
    ∇
```

```
    ∇ R←A GENDUR B
      ⍝  GENERATION OF ACTIVITY DURATION
      PARAM←,((DURACT[;1 2 3]∧.=(B[2 3],A)))/[1]DURACT[;3+⍳5]
      PAR←1↓PARAM
      R←∈(DISTRIB[(PARAM[1]);])
    ∇
```

```
    ∇ R←AVGE A
      ⍝  DURATION OF ACTIVITY BASE ON AVERAGE ELAPSE TIME
      ⍝
      R←PAR[1]
    ∇
```

```
    ∇ R←NRML A
      ⍝  GENERATION OF A VARIABLE ACCORDING TO A NORMAL DISTRIBUTION
      ⍝
      R←(?100 100)÷100
      R←((¯2×⍟R[1])*0.5)×2○2×○R[2]
      R←A[1]+A[2]×R
      R←R⌈A[3]
      R←R⌊A[4]
    ∇
```

```
    ∇ R←UNFR A
      ⍝  GENERATION OF A VARIABLE ACCORDING TO A UNIFORM DISTRIBUTION
      ⍝
      R←A[1]+(?-/A[2 1]×100)÷100
    ∇
```

```
    ∇ R←EXPON A
[1]   ⍝ GENERATION OF A VARIABLE ACCORDING TO AN
[2]   ⍝     EXPONENTIAL DISTRIBUTION
[3]   R←-A[1]×⍟(?100)÷100
[4]   R←R⌈A[2]
[5]   R←R⌊A[3]
    ∇
```

```
    ∇ REPLACE A
[1]   ACT[A[1];]←A
[2]   →(~TRACE)/0
[3]   '    ',MACH[A[2];],,'I3,I3,I6,⎕ HR:⎕,F7.2'⍙FMT 1 ÷ρA[1 3 4 5]
    ∇
```

```
    ∇ SIM1S
[1]   'PROJECT:    ';PROJET
[2]   'SIMULATION:';PASSE
[3]   'DATE:       ';DATE
    ∇
```

```
    ∇ A SI B
[1]   →(B×2)
[2]   0ρ∊A
    ∇
```

```
    ∇ REP←L QA T
[1]   T,NLF
[2]   REP←L↑⍞
    ∇
```

```
    ∇ REP←L QN T
[1]   T,NLF
[2]   REP←L↑∊⍞
    ∇
```