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A Survey of Timber Harvesting Simulation Models for Use in the South

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SUMMARY

Nine forest harvesting simulation models with potential for simulating southern operations are reviewed in detail. An annotated bibliography of associated forest harvesting simulation literature is appended. From the nine models, five appear useful enough to warrant further analysis. They are: 1. Forest Harvesting Simulation Model (FHSM) developed at Auburn University; 2. Full-Tree Field Chipping and Transport Simulator (FTFC) developed at USDA Forest Service North Central Forest Experiment Station; 3. Harvesting System Simulator (HSS) developed by the American Pulpwood Association; 4. Simulation Applied to Logging System (SAPLOS) developed at the USDA Forest Service northeastern Forest Experiment Station; 5. Timber Harvesting and Transport Simulator (THATS) developed at the USDA Forest Service Northeastern Forest Experiment Station.

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INTRODUCTION

The Southern States produce 45 percent of the total roundwood harvested in the United States. This percentage is expected to grow to 50 percent by the year 2000. During the same period, 4 million acres of commercial forest lands will be lost to other uses. So, much further production will have to come from poor or fragile sites and from small tracts, sites that cannot now be productively managed unless alternative harvesting systems are developed. The possible interrelationships among production, cost, and energy usage for both present and future harvesting systems need to be evaluated. Computer simulation is one possible evaluation strategy. A systems simulation model for the southern harvesting operations would assist in this analysis.

As a first step in using simulation for analysis of southern harvesting systems, we conducted a literature survey to identify existing models, to determine their stage of development, and to evaluate their capability for modeling southern operations.

We found that many timber harvesting simulation models have been developed in North America in the last 10 to 15 years. Some of the models are complete systems models (2, 3, 6, 8, 10, 11,13, 16, 18, 21, 23, 25, 26). Others model particular phases of the harvesting operation (1, 4, 7, 12, 20, 24). Some models are fully developed (6, 9, 11, 13, 16, 18, 23, 25), while others are being refined (3, 22). Though most models have been developed for conditions outside the South, we found nine systems-simulation models that showed potential for modeling southern harvesting operations, and they are reviewed here. Many other models that focus on machine or other related simulation were also found. These models are documented in the appendix.

SYSTEMS MODELS

Auburn Pulpwood Harvesting System Simulator

The Auburn Pulpwood Harvesting System Simulator (APHSS) is a FORTRAN-based, time-oriented simulation of southeastern pulpwood harvesting systems. The model was developed by William H. Bussell, James N. Hool, Alfred M. Leppert, and Grady Harmon, all of Auburn University, Auburn, Alabama. The model, as expanded and refined by Robert Osborn, is available through Hool. Both development and refinement were sponsored by the Southern Executives Association.

Bussell et al. (8) document the design parameter of APHSS and divide the harvesting operation into a production phase and a transportation phase. Only the production phase, which consists of felling, limbing and topping, skidding, bucking, bunching, and

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loading, is simulated. Interactions between operations are modeled with the use of buffer inventories. Average cycle times on each operation are used, making the model deterministic. A uniform time increment advances the simulated clock, with simulation variables updated at each time increment. Three reports are generated: end of hour, end of day, and end of week, the latter two involving a cost-per-log-produced statement as well as production.

Bussell et al. (9) document the usefulness of APHSS by placing observed average operating times into the model and adjusting the system configuration for maximum wood production. One system is extensively studied and reported.

Osborn (23) modified APHSS to simulate a variety of pulpwood harvesting systems and added a transportation phase to the model (fig. 1). Critical assumptions and restrictions are as follows:

1. An unlimited number of trees are available for felling.
2. All trees are the same size.
3. All systems components of the same type create a common inventory.
4. Each component is confined to a particular function.
5. Each component in a system operates independently.
6. All system irregularities are reflected in cycle times.
7. All configurations are limited to a maximum of six components (excluding transportation).
8. All component cycle times must be evenly divisible by the specified uniform time increment.

Three example systems are simulated.

COMPONENTS	CONFIGURATION													
	SHORTWOOD								LONGWOOD					
FELLING	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LIMBING	X	X	X	X					X	X	X			
SKIDDING	X	X			X	X			X	X		X	X	
BUCKING	X	X	X	X	X		X	X						
BUNCHING	X		X		X	X	X		X		X	X		X
LOADING	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TRANSPORTATION	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Figure 1.—Configurations of the Osborn Modified APHSS model.

Forest Harvesting Simulation Model

The Forest Harvesting Simulation Model (FHSM) is a general, event-oriented timber and pulpwood harvesting simulator developed by Dennis B. Webster and expanded and refined by John R. Killham, both of Auburn University. The model is modular in that functional elements, felling, limbing,etc., act as building blocks and can be arranged in various combinations. Consequently, the model can be tailored to the specific harvesting operations. The model, available through Webster, is written in FORTRAN and uses GASP II for its executive control.

Webster (26) details the following design parameters for simulating the major types of saw-log and pulpwood-harvesting operations in the South.

a. The simulator should be flexible enough to duplicate the major harvesting operations used in timber-harvesting systems in the South.
b. The model should be detailed enough to allow for possible analyses of individual harvesting operations.
c. The model should possess a high degree of believability in the way it duplicates a system's operation.

To satisfy the first design parameter, FHSM simulates the functional elements of various harvesting operations, such as felling, limbing, etc. The model for a particular system, a configuration in Webster's terms, can be assembled by collecting the functional elements that constitute the operation.

To satisfy the second design parameter, each functional element allows different pieces of equipment to perform the same task while differentiating each piece's characteristics and capabilities. For example, two different skidders in the skidding phase could be used.

To satisfy the third design parameter, wood flow in the model matches the actual wood flow in a harvesting operation. A tree or its parts are maintained as identifiable units from selection for felling until deposition at the mill. We call this wood flow property "continuous across processes." Webster uses two configurations as pilot demonstrations of the model's capabilities.

Killham (16) expanded Webster's basic design and pilot system into a working model. He considers ten timber harvesting configurations, six for sawtimber and four for pulpwood. Each

configuration in FHSM is a combination of some of all eight basic harvesting processes—felling, limbing, bucking at the stump, skidding, bucking at the landing, loading, hauling, and unloading, and is identified in figure 2.

OPERATIONS	CONFIGURATION									
	SAWTIMBER						PULPWOOD			
FELLING	X				X	X	X	X		
LIMBING	X				X	X	X	X		
FELLING & LIMBING		X	X	X					X	X
BUCKING AT THE STUMP	X	X					X		X	
SKIDDING	X	X	X	X	X	X		X		X
BUCKING AT THE LANDING			X			X		X		X
LOADING	X	X	X	X	X	X	X	X	X	X
HAULING	X	X	X	X	X	X	X	X	X	X
UNLOADING	X	X	X	X	X	X	X	X	X	X

Figure 2.—Configuration of FHSM.

The configuration acts both as an operations design or tailoring parameter, and as a simulation's run-time control parameter, which identifies the subroutines in the computer program to be used. Hence, both the design and the execution of the model are modular, that is, only those building blocks that identify the configuration are used. The working model allows for a unique description of the operating characteristics for each man and machine unit involved in harvesting operation. These characteristics are averages or empirical distributions collected from time and motion studies, so there is complete flexibility in determining the harvesting elements within the model. For example, fellers with chain saws and mechanical shears can be operating together. Operating statistics in terms of production units and time are collected on each man and machine unit modeled. The specification of individual man and machine units and the collection of operating statistics on these same units permit a detailed analysis of individual harvesting operations.

The forest data and the continuous wood flow give the model a high degree of believability. The forest data are generated from a standard timber cruise, and consist of total number of trees to be harvested, average spacing between trees, percentage of total that is pine, diameter class distributions, merchantable height distributions, and defect distributions for sawtimber logs. Continuous wood flow maintains that the output in terms of pieces (trees or parts) from one process (e.g. felling) is the input for the next process (e.g. limbing).

The output reports are in terms of production units, (e.g. number of trees felled, total board feet delivered to the mill) and processing times. The model contains no economic analysis.

Full-Tree Chipping and Transport Simulator

The Full-Tree Chipping and Transport Simulator (FTFC) is a package of two GPSS/360 simulation models, one for chipping and one for transport, designed to simulate in-woods full-tree chipping. The models were developed by Dennis P. Bradley, Frank E. Biltonen, and Sharon A. Winsauer, of the USDA Forest Service North Central Forest Experiment Station, St. Paul, Minnesota, and are available from the Station.

Bradley et al. (6) describe a simulation that both models the activities of feller-bunchers, skidders, a chipper, trucks and vans in the field, and models dumping and scaling at the mill. The stand to be harvested must be provided by the user in the form of (x,y) coordinate location of trees, volume of each tree in the stand, and felling order for the feller-buncher. The model keeps individual tree identity until the tree is chipped and blown into the van. Machine interactions have been carefully considered so that one skidder can "see" another in the woods and will not interfere with it. Start-up and shut-down conditions for each day can be specified.

Three trucking situations are modeled in the transport segment:

Situation 1.

a. There are no terrain and road problems; highway tractors with vans can drive directly to the chipper without assistance.
b. Setout trucks for handling empty and full vans are not required, because either
   (1) there are no extra vans, or
   (2) there are extra vans but the number of slots at the chipper equals or exceeds the total number of vans.

Situation 2.

a. There are still no terrain or road problems; highway tractors can get

to the chipper without assistance, but

b. One or more setout trucks are required some of the time because both of the following conditions are true:
   (1) there are extra vans and
   (2) the number of slots at the chipper is less than the total number of vans.

Situation 3.

a. Terrain and/or road problems prohibit the highway trucks from bringing empty vans to the chipper. They must drop empties and pickup full vans a considerable distance away.

b. One or more setout trucks must therefore do all the work of moving empty and full vans to and from the chipper. Setout trucks in this situation are probably specially modified dozers or skidders with a fifth wheel.

The model's report generator provides detailed production and cost statistics by operation, system energy consumption, and net energy produced, the latter two in the form of BTU's.

Bradley and Winsauer (7) focus on the last stage of a harvesting operation, chipping and hauling to the mill. Their model attempts to determine the optimal combination of men, trucks, vans, and operating rules for the observed chipping rate. Their model has five segments: 1) chipper, 2) trucks and vans, 3) setout trucks, 4) a mill yard, and 5) records. Wood is assumed to be presented to the chipper by a "black box" operation that allows the chipper to fill vans at a variable rate. The model's report generator produces a statement of the system characteristics and production, and cost statistics. Two examples, one a case study and one a hypothetical case, are presented.

The Georgia Tech Model

The Georgia Tech model is the first result of a research grant awarded in 1967 by the Southern Executives Association to Georgia Institute of Technology to study the systems aspects for pulpwood harvesting and transportation. The research requirements were to structure a systems model that validly represents the significant characteristics of and constraints on present systems, and on systems that may appear up to the year 2000. The GPSS model, developed by Stark (25), is one of the earliest attempts at simulating the forest harvesting system. Strong emphasis in his work was placed on production of 5'3" pulpwood in the South. Twenty-eight different harvesting configurations, which represent the small pulpwood producer's operations, are modeled (figs. 3, 4).

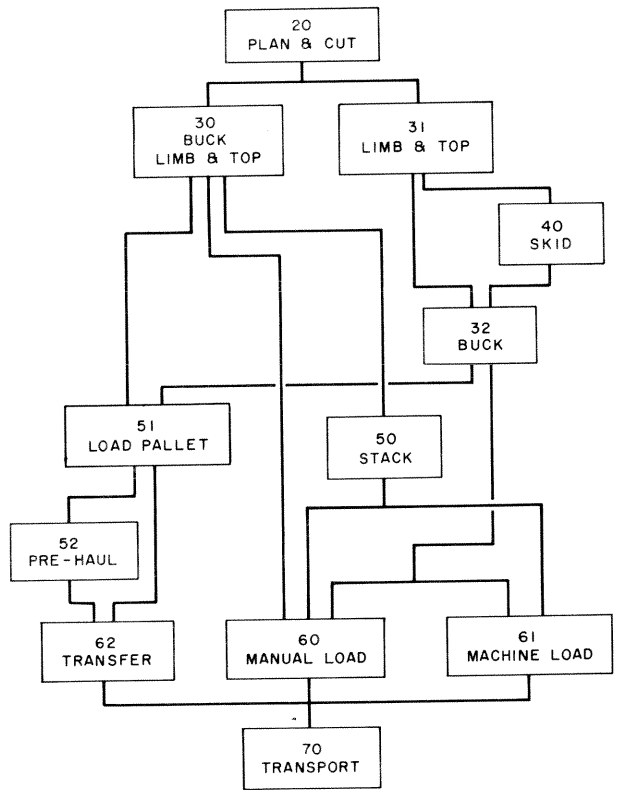

Figure 3.—A flow diagram of basic 6'3" pulpwood harvesting operations.

The Harvesting System Simulator

The Harvesting System Simulator (HSS) is a FORTRAN-based simulation program designed to simulate the productive and nonproductive activities (down time, breaks, etc.) of a harvesting system. The model was developed by the American Pulpwood Association during the late 1960's and early 1970's under their Harvesting Research Project. In 1974 APA

System No.	Harvesting Operation Number Sequence							
1.	20	31	32	51	52	62	70	
2.	20	40	31	32	51	52	62	70
3.	20	31	40	32	51	52	62	70
4.	20	30	51	52	62	70		
5.	20	40	30	51	52	62	70	
6.	20	31	32	51	62	70		
7.	20	40	31	32	51	62	70	
8.	20	31	40	32	51	62	70	
9.	20	30	51	62	70			
10.	20	40	30	51	62	70		
11.	20	31	32	61	70			
12.	20	40	31	32	61	70		
13.	20	31	40	32	61	70		
14.	20	30	50	61	70			
15.	20	40	30	50	61	70		
16.	20	31	32	50	61	70		
17.	20	40	31	32	50	61	70	
18.	20	31	40	32	50	61	70	
19.	20	31	32	60	70			
20.	20	40	31	32	60	70		
21.	20	31	40	32	60	70		
22.	20	30	60	70				
23.	20	40	32	60	70			
24.	20	32	50	60	70			
25.	20	40	32	50	60	70		
26.	20	31	32	50	60	70		
27.	20	40	31	32	50	60	70	
28.	20	31	40	32	50	60	70	

Figure 4.— Possible combinations of harvesting operations in the Georgia Tech model.

released HSS to Virginia Polytechnic Institute and State University, Blacksburg, Virginia, where it remains.

The American Pulpwood Association's User Guide (2), though somewhat out-of-date relative to format and input characteristics, provided a good description of the workings of HSS from the user's point of view.[1] It details the kinds of inputs necessary, defines these, and states their interrelationships. The three parts of the program package (the simulator, the two report generating programs-production and operations report, and the cost analysis report) are explained.

O'Hearn (21) describes the current status of HSS. A maximum of 14 machines, working in any combination, and a maximum of six aggregations of like machines (phase) can be simulated. The harvested tract can be divided into a maximum of 14 harvesting areas that can differ in stand type, volume per acre, species composition, and skidding distance to the primary landing. Individual harvesting areas have no acreage or volume limits. Unique production rates may be specified for each harvesting area-machine combination. The user controls the order in which harvesting areas are processed. Terrain and stand limitations are modeled through move or travel rate modifiers and deck locations. Wood flows from phase to phase in aggregated volumes.

Nonproductive activities, such as machine failures, breakdowns, delays, and servicing, can be imposed logically or stochastically. Repairs can be made at the stump, the deck, or the shop. Repairs at the stump hold the machine in place, while repairs at the deck or shop require the machine to move to the primary deck. Delays are divided into two types major and minor. Major delays bring the machine back to the deck, while minor delays leave it in place. A distribution between productive and nonproductive time can be provided.

Program output is provided by two report generators that can be called on separately or jointly. They provide time, production, cost, and revenue statistics. Also, discounted cash flow and return on investment analysis can be made. All output reports are detailed and complete.

A Method for Analyzing Environmental Effects of Impacting Activities.

A Method for Analyzing Environmental Effects of Impacting Activities, a FORTRAN/GASP IV model, simulates, in two phases, the effect of an impacting activity on the ecosystem (11). Phase one, the impacting activity, is modeled in the microphase and can be used by itself for detailed study of the activity. The three impacting activities modeled are timber harvesting, road building, and fire. For timber harvesting, SAPLOS[2] is used. Phase two, the ecosystem, is modeled in the

[1]A new User Guide is nearing completion under the direction of W.B. Stuart, VPI & SU, Blackburg, Va.

[2]SAPLOS is documented later in the report as a separate model and will not be repeated here.

macrophase and simulates the dynamic response of the ecosystem to the impacting activity. The six subsystems that model the ecosystem are area, moisture-water, timber, forage, wildlife, and erosion. The model was developed by Louis T. Egging at Montana State University, Bozeman, Montana, and is available from him.

Residues for Power

Residues for Power (REPO), a SIMCOMP[3] model, evaluates systems for handling logging residues for fuel. The model was developed by B. Bruce Bare, Benjamin A. Jayne, and Brian F. Anholt, at the USDA Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, and is available from the Station.

Bare et al. (3) report the basic objective is to simulate the transfer of harvesting residues, in the form of chips, to a hypothetical power plant. Various combinations of skidding, loading, transporting, unloading, sorting, and chipping are examined (the exact combinations are not documented). Rate functions, for example volume per unit time, govern the materials flow from operation to operation. Stores of materials between operations model the materials in process and the influence of one operation upon another.

REPO is a fixed time increment model with a 9-hour workday as the unit of measure. Tracking of activities within one workday is not possible, nor can the model account for machine interactions within this time period. However, the serial nature of the operations will not allow following operations to be simulated until all preceding operations have been completed.

Though developed as a residue handling model, REPO is actually a more general materials handling model that can be used to simulate a timber harvesting and transportation system.

[3]The SIMCOMP programming language is a machine-dependent simulation language written at Colorado State University for the CDC 6400 computer. The language is designed for compartment-oriented simulation models. Programming in SIMCOMP requires an understanding of the FORTRAN IV language, since the SIMCOMP compiler creates a FORTRAN program which is compiled by the CDC Extended FORTRAN compiler.

Simulation Applied to Logging Systems

Simulation Applied to Logging Systems (SAPLOS) is a general logging simulation model adaptable to a variety of logging configurations. Begun in 1971 in a FORTRAN and GASP II version, it has been changed to a FORTRAN model with GASP IV providing executive control of the simulation. The model was developed by Leonard R. Johnson, Donald L. Gochenour, Jr., and Cleveland J. Biller at the USDA Forest Service Northeastern Forest Experiment Station, Morgantown, West Virginia, and is available from the Station.

Johnson's model (12), a precursor of SAPLOS, is a FORTRAN and GASP II simulation of the materials handling problem involved in the loading and hauling phases of a timber harvesting operation. Johnson's objective is to produce a cost estimate, in terms of equivalent annual costs, by which different loading and hauling systems can be compared. The material handling operations are simulated, and production statistics are gathered. From these, and machine operating cost data, an equivalent annual cost is computed. Both the production statistics and equivalent annual costs are documented in the report generator.

Johnson et al. (15) document the first work on SAPLOS and identify the model's design parameters. SAPLOS' development progressed through three phases of work: 1) identifying and classifying the prevelant logging system configurations in Appalachia and their interaction points, 2) within a subsystems general operation, determining the sequence of activities defining the operation, 3) combining activities of the subsystems into events in the computer model. In the first phase, Johnson et al. found that Appalachian logging systems predominately involve felling, skidding, loading, and hauling; some systems may include bucking and pre-bunching. These six subsystems represent the standard operations for SAPLOS. Felling and bucking are the production functions of the logging systems, while skidding, loading, hauling and prebunching are considered material-handling operations. When the events of two logging operations overlap, a point of possible interference occurs. These points are considered "critical locations" on the ground and form control points in the model, signaling the beginning and ending of model activities. The

model is written in FORTRAN with GASP II providing control of the simulation.

Biller et al. (5) use SAPLOS to compare three different systems logging the same site under identical stand conditions. The systems are:

1. A ground system with a crew of three. The operation is comprised of a feller who uses a chain saw and doubles as a choker setter; a wheeled skidder operator; and an operator of a self-loading, trailer truck.
2. A ground system with a crew of seven. One man fells with a chain saw. For skidding there are two skidder operators and two choker setters. Two self-loading trucks are used for hauling.
3. A skyline system with a crew of eight. The skyline yarder operator and a rigging boss perform the skidding operation along with two choker setters and a chaser. The other three men, a sawyer and two truck drivers, perform as in the second system.

Johnson and Biller (14) add the in-woods, full-tree chipping operation to SAPLOS. Three situations for an in-woods, full-tree chipping operation are presented. Each is then balanced, with time and cost per cubic foot of chips produced as the balancing criteria. The objective of this demonstration is to show how simulation can be used as a tool for the manager in setting up in-woods, chipping operations.

Johnson (13) presents SAPLOS' final version, which follows the design parameters specified in (15). In the design five critical locations are identified where logging operations can interact and are modeled as the key division points. The activities necessary to deliver logs to these points are modeled by identifying equipment and end of service events at each location. The resulting model can simulate logging systems varying from small pulpwood crews to west coast skyline operations to in-woods chipping systems.

Specifically, the different configurations of logging operations possible can be summarized by listing the activities modeled at each critical location, and putting them together in various combinations. The activities are:

(1) Felling: Manual tree length
Manual with bucking in the woods
Mechanical (shears)

(2) Bucking: In woods by feller
At landing
Haul tree length (no bucking)

(3) Skidding: Prebunching logs to skid road
Ground skid from woods or road to landing
Cable yarding

(4) Loading: Separate loading unit
Loader mounted on hauling unit
Whole tree chipping

(5) Hauling: Straight haul to mill
Prehaul to docking area

To run the model, the user must write two system specific subroutines, TRESZ (tree size) and DISTM (distance and time). TRESZ is used to find or generate tree volumes, diameters, and lengths. The tree parameters are generated by: 1) determining a butt diameter, 2) based on the butt diameter, producing a merchantable tree height, and 3) then calculating the tree volume as a function of butt diameter and height. The resulting parameters should depict the stand to be harvested. TRESZ is called and a tree is produced as needed.

Any time a distance or a production time is needed, DISTM is called and the necessary item is generated. The distance and time generators reflect the stand and operating conditions of the logging operations being simulated.

The report generator gives detailed production and cost statements by activities and for the process as a whole.

Timber Harvesting and Transport Simulator.

The FORTRAN-based Timber Harvesting and Transport Simulator (THATS) simulates the standard harvesting configuration of felling-limbing-topping, bunching, skidding, bucking, loading, and hauling. THATS was developed by A. Jeff Martin at the USDA Forest Service Laboratories in Princeton and Morgantown, West Virginia, and is available from Martin upon request.

Martin (17) examines the potential of computer simulation as a tool for forest management work. He presents a harvesting operation analysis that includes costs, production, balance, and a sensitivity analysis on the

number of elements (e.g. fellers) in the production components.

Martin (18) describes the structures, methodology, and main components of THATS. THATS is built around a main program composed of eight components (felling, bunching, skidding, bucking, loading, hauling, roadbuilding, and cost accounting) and a "clock." The model is a time oriented simulation in which simulated time on the clock is advanced one minute, then checks are made for active events.

Simulated event times are generated either from given averages and standard deviations, or from event times produced by a regression equation developed from collected data. All random variable event times have either a normal or a log normal distribution. If any skewing is present in the time study data, the log normal distribution is used. Regression equations from data collected for Appalachian logging operations are contained in the report.

The system simulates one day at a time and shuts down at the end of the working day in a staggered manner, with each crew finishing the day close to quitting time, though depending on the task at hand, some may be a little early and some may be a little late.

Wood flows through the model in a volumetric manner. The input to an operation is a tree or a piece of a tree, and the output from the operation is a volume. The next operation draws trees or pieces from the deposited output volume, but these new trees or pieces have no relation to the input trees of the first operation except that their total volume equals the deposited output volume. For example, a tree is generated for the felling operation, felling statistics are collected on that tree, and the volume of that tree is deposited for the bunching operation. The bunching operation will now generate new trees up to the volume of the felled trees deposited.

A User's Guide for THATS, Martin (19), contains a detailed description of each input

CHARACTERISTIC / MODEL	GENERAL PARAMETERS																																				
	LANGUAGE	CONTINUITY ACROSS PROCESSES	FLEXIBILITY:	PULPWOOD	SAWTIMBER	CHIPPING	PLYWOOD	INPUTS:	OPERATING COSTS	OPERATING TIME	CAPACITIES	LONG RUN COSTS	STAND PARAMETERS:	(X, Y) TREE LOCATION	TREE VOLUME	DBH	MERCHANTIBLE HEIGHT	TREE DENSITY	TOTAL NUMBER OF TREES HARVESTED	SPECIES	AREA TO BE HARVESTED	SLOPE	TERRAIN	OUTPUTS:	PRODUCTION (AMOUNTS)	PRODUCTION TIMES	ECONOMIC	DELAYS:	SCHEDULED (LUNCH, etc.)	LOGICAL (SYSTEM)	STOCHASTIC (BREAKDOWNS, etc.)	SPECIAL PROBLEMS CONSIDERED:	ENVIRONMENTAL	RESIDUE PROCESSING	TRANSPORTATION	ROAD BUILDING	DAILY START UP & SHUT DOWN CONDITIONS	INTERACTIONS WITH BUFFER INVENTORIES
APHSS	FORTRAN	X		X	X				X	X	X				X		X								X	X	X		O	X	O							X
FHSM	GASP II	X		X	X					X	X					X		X	X	X					X	X			O	X	O							X
FTFC	GPSS	X		X		X			X	X	X			X	X	X	X	X			X				X	X	X		O	X	O				X		X	
GEORGIA TECH	GPSS	X		X						X	X					X		X	X			X	X		X													X
HSS	FORTRAN	O		X	X	X	X		X	X	X	X			X			X	X		X		X		X	X	X		X	X	X						X	X
EGGING'S	GASP IV	O		X	X	X	X		X	X	X	X		X	X	X	X		X		X	X			X	X	X		X	X	X		X				X	
REPO	SIMCOMP	X				X			X	X	X				X				X		X	X			X	X	X		X	X	X			X		X	X	X
SAPLOS	GASP IV	O		X	X	X	X		X	X	X	X		X	X	X	X		X		X	X			X	X	X		X	X	X						X	
THATS	FORTRAN	O		X	X				X	X	X				X	X	X		X						X	X	X		X	X	X					X	X	X

KEY

X – CONSIDERED IN MODEL
BLANK – NOT APPLICABLE FOR MODEL
O – SHOULD BE CONSIDERED
A – USES AN AVERAGE
D – USES A DISTRIBUTION
D⟶ – ONE DISTRIBUTION SPANS THE ACTIVITIES
A⟶ – ONE AVERAGE SPANS THE ACTIVITIES

Figure 5.—Comparison of system simulation models.

needed to run THATS, a random number generating routine, a list of all variables used, and a source listing of the complete THATS code.

COMPARISON OF SYSTEMS MODELS

The nine models examined are compared and contrasted in figure 5. The first result evident from examining figure 5 is that no consensus exists on what constitutes the essential elements of a forest harvesting model. Forest data, for example, run the complete gamut from all trees being of a single volume and merchantable height (APHSS) to trees located by (x,y) coordinates, and given a d.b.h., merchantable height, and volume (SAPLOS). Some models address a single harvesting system (pulpwood in the Georgia Tech Model), and others have a multiplicity of systems (SAPLOS, HSS, FHSM).

The second item of major importance reflected in figure 5 is that there is great variety in the detail simulated in the models. This variety reflects the point of view of the modeler and must be given careful consideration when selecting a model for use. Timber flow, for example, occurs in essentially two ways: (1) a tree is harvested, its volume determined and deposited in an inprocess volume pool, and the identity of the tree is lost, (HSS, Egging's, SAPLOS, THATS); (2) tree parts maintain their identity and characteristics from stump to mill (FHSM, Georgia Tech, FTFC).

Lastly, input requirements and output information can only be given in gross terms. For example, although all models use "operating time" as an input, precisely what kind of operating time (average, distribution, regression equation) is not identified. A similar statement could be made for the output parameter "production amounts." Consequently, each model needs to be examined for its input/output characteristics.

CHARACTERISTIC / MODEL	OPERATIONAL PROCESS	FELLING:	TRAVEL TIME/SPEED TO TREE	FELLING TIME	EQUIPMENT:	CHAIN SAW	SHEAR	GENERAL	LIMBING - TOPPING:	TRAVEL TIME/SPEED TO TREE	LIMBING TIME	EQUIPMENT:	CHAIN SAW	GENERAL	BUCKING:	TRAVEL TIME/SPEED TO TREE	BUCKING TIME	DEFECTS CONSIDERED	EQUIPMENT:	CHAIN SAW	GENERAL	BUNCHING:	TRAVEL TIME/SPEED TO TREE	BUNCH ACQUISITION TIME/SPEED	TRAVEL TIME/SPEED TO DROP	DROP TIME/SPEED	BUNCH VOLUME LIMIT	BUNCH STEM LIMIT	EQUIPMENT:	MECHANICAL	MANUAL	GENERAL
APHSS				A		X				A→			X				A			X			A→							X		
FHSM			A	A				X		A	D			X		A	D	X		X		O										
FTFC			D	D			X																				X	X				
GEORGIA TECH			D	D				X			D			X			D			X			A→							X	X	
HSS			D	D				X		D	D			X		D	D				X		D	D	D	D						X
EGGING'S				D		X	X		X*								D				X		D	D	D	D				X		
REPO																																
SAPLOS				D		X	X		X*								D				X		D	D	D	D				X		
THATS			A	D				X			D			X			D			X				D								

* INCLUDES WITH FELLING

Figure 5.—Comparison of system simulation models—Continued.

CHARACTERISTIC / MODEL	SKIDDING:	CHOKE TIME/SPEED	INHAUL TIME/SPEED	UNCHOKE TIME/SPEED	OUTHAUL TIME/SPEED	WEIGHT LIMIT	VOLUME LIMIT	STEM LIMIT	EQUIPMENT:	SKIDDERS	SKYLINE	LOADING:	GRAB TIME/SPEED	SWING TIME/SPEED	DROP TIME/SPEED	LOADER REPOSITION TIME/SPEED	TRUCK REPOSITION TIME/SPEED	SORTING TIME	HAULING:	TRACTOR/TRAILOR/VAN POSITIONING TIME	HOOK UP TIME	UNIMPROVED ROAD HAULING TIME/SPEED	IMPROVED ROAD HAULING TIME/SPEED	SCALING TIME	UNLOADING TIME	RETURN TIME/SPEED	UN-HOOKING TIME	EQUIPMENT:	CHIP VANS	TRACTOR TRAILORS	BOBTAIL TRUCKS
APHSS		A→		O	A			X		X			A→							A→										X	
FHSM		A	D	A	D	X				X			D→			A	A	A		A		A	A	D	D	A				X	X
FTFC		D	D	D	D		X	X		X			D	D	D	D				D	D	D	D	D	D	D	D		X		
GEORGIA TECH		D→					X			X			D→									D	D		D					X	X
HSS		D	D	D	D					X			D→			D						D	D			D			X	X	X
EGGING'S		D	D	D	D		X	X		X	X		D→								D	D	D				D		X	X	X
REPO		D	D	D	D			X		X	X		D→					D				D	D		D	D			X	X	
SAPLOS		D	D	D	D		X	X		X	X		D→								D	D	D				D		X	X	X
THATS		D	D	D	D		X			X			D→				D					D→			D	D				X	X

Figure 5.—Comparison of system simulation models—Continued.

SELECTION OF PRIMARY MODELS FOR FURTHER STUDY

After examining the literature and comparing the properties of each model, we removed APHSS, the Georgia Tech Model, Egging's model, and REPO from further consideration. APHSS is a deterministic model that uses only averages for operational parameters, and hence cannot model the stochastic nature of the harvesting operation. The Georgia Tech Model, though the first step in a complete systems analysis, is outdated and needs to be redeveloped for today's systems. Egging's model, though it contains some interesting environmental modeling, uses SAPLOS for the timber harvesting portion, so the portion of interest in this search is contained in SAPLOS and can be studied there. REPO is claimed to be a general materials handling model built around the idea of simulating the residue handling process, but converting the model into a harvesting systems model would require much additional work. Also, the model is written in a machine dependent computer language that makes using it on other computers difficult.

The remaining five models have the best potential for modeling most of the southern operations with provisions for expansion to additional configurations not included now. No model, either completed or planned, contains all southern forest harvesting operations. The potentials of these five models are:

1. FHSM is specifically designed to model the southern operations. Though incomplete, the model has the basic structure for an accurate and realistic description of the harvesting operations. The modularity of design makes additions and modifications to the model relatively straightforward.
2. FTFC represents the only complete analysis of in-woods, full-tree chipping. HSS and SAPLOS each contain a chipping configuration, but neither is as detailed as Bradley's model.
3. HSS is the most detailed of all the models examined. Most of the southern

harvesting operations have been considered. The interaction of events has been modeled carefully. Production, delay, and cost reports permit analysis of the harvesting operation from many different points of view.

4. SAPLOS is a generalized harvesting simulation model adaptable to a variety of logging situations. The model contains most southern harvesting operations.
5. THATS, though limited to a single harvesting configuration, is a complete analysis of that configuration for the Appalachian region. Also, the model contains a roadbuilding operation not found in the other primary models.

Published literature does not contain sufficient information to assess each model fully. We have initiated a follow up study to provide an in depth analysis of each model's strengths, weaknesses, computer codes, input data requirements, output data information, and capabilities for modeling the southern operations.

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APPENDIX

ASSOCIATED HARVESTING SIMULATION LITERATURE

Almquist, Anders.
1968. A simulation model for feller-bunchers, Ekonomi 7 Forskningsstiftelsen Skogsarbeten (Logging Research Foundation), Stockholm, Sweden, 4 p.

The feller-buncher model—which consists of two parts, a stand model and a machine model—is Newnham's (1967a) model modified for Swedish conditions. The machine is made to operate in the stand generated by the stand model. The manner in which the feller-buncher proceeds through the stand is governed by a set of decision rules that make it independent of the modeler. The model tests machine characteristics and harvesting strategy, but cannot take different terrain features into consideration.

Bertils, Bertel Randolph.
1969. A GPSS II model to evaluate terrain

capabilities of typical pulpwood harvesting vehicles, M.S. Thesis, Ga. Inst. of Tech., Atlanta. 95 p.

This thesis proposes to pulpwood producers a means to evaluate, before purchase, how well typical pulpwood harvesting transport vehicles perform in various terrain conditions. The model uses the physical and operational characteristics of the vehicle as input parameters and "traverses it" across five typical terrain types found in the Georgia pulpwood harvesting areas. The vehicle is evaluated under four conditions in each terrain type: (1) soft soil mobility, (2) stability with respect to slope and soil microge metry, (3) vegetation obstacles, and (4) terrain obstacles of, or caused by, hydrology.

Bertils conducted two experiments to give the pulpwood producer a measure of the effectiveness of each machine in each terrain type. The first experiment determines with a probability, the percentage of resource areas the producer could harvest before his vehicle is overcome by terrain obstacles. The second determines if tire size causes differences in vehicles performance.

Corcoran, Thomas J.
1971. Timber harvesting system design and equipment leveling through GPSS/360. Trans. of ASAE, 14:248-252.

Corcoran advocates GPSS as a tool for rigorous planning in timber harvesting systems. Models in GPSS can be made modular so that each machine is a miniature simulation. He also believes the language is ideally suited for those who have the most knowledge of the actual system to be simulated. Thus, the model may be created mostly by professionals in subject-matter fields that relate to the technical features of the system and not necessarily by specialist computer programmers.

Newman, Lawrence C.
1975. Direct loading with the Koehring harvester—a simulation model. For. Manage. Inst., Ottawa, Ontario, Inf. Rep. FMR-X-83. 3 p.

The purpose of Newman's FORTRAN simulation is to see if a change in the use of Koehring harvesters from stockpiling to direct loading onto hauling vehicles would reduce cost of pulpwood delivered to the mill.

Newnham, R. M.
1967a. A progress report on the simulation model for pulpwood harvesting machines. For. Manage. Res. and Serv. Inst., Ottawa, Ontario, Inf. Rep. FMR-X-6. 41 p.

A simulation model for a feller-buncher passing through a pulpwood stand is presented. Stand and machine characteristics are the input parameters. Outputs break down the harvesting time into traveling, felling and bunching, unloading and non-productive. The position of each sweep and the number of trees and volume felled in each sweep are also produced.

The model is designed to help cut time and costs spent developing and testing prototype feller-bunchers. The initial machines simulated are of the Beloit type tree harvester and LRA feller-bunchers. Because these machine types have a swing boom with an attached shear, the machine passes through the stand in a straight line.

Newnham, R. M.
1967b. A FORTRAN programme to simulate pulpwood harvesting machines. For. Manage. Res. and Serv. Inst., Ottawa, Ontario, Inf. Rep. FMR-X-7, August. 32 p.

This report describes the FORTRAN program and its use for the above model, (Newnham 1967a).

Newnham, R. M.
1968. Simulation of pulpwood harvesting machines. Proc.: For. Eng. Conf., East Lansing, Mich. Sept. 25-27. p. 71-73.

The feller-buncher model annotated in Newnham (1967a) has been expanded to model fixed shears of the Suicard VFB, Roanoke, and Fleco types. These shears are usually mounted on the front of wheeled or tracked vehicles. They have no boom, and each tree to be felled must be approached individually. As a result, the machine "wanders" through the forest instead of traveling in a straight line.

A model for mechanized thinning is also introduced. The model uses a B-105 Feller-Processor for the thinning operation. This machine has a swing boom with attached shear that reaches out and cuts each tree. The harvesting pattern for the B-105 is a modified version of the Beloit-LRA model in which trees directly in the path of the harvester and to the side and rear are harvested. A new variable "crown resistance" has been introduced into the model.

Newnham, R. M., and S. Sjunnesson.
1969. A FORTRAN program to simulate harvesting machines for mechanized thinning. For. Manage. Res. Serv. Inst., Ottawa, Ontario, Inf. Rep. FMR-X-23. 48 p.

The FORTRAN program to simulate the mechanized thinning operation annotated in Newnham (1968) and its use are given.

Newnham, R. M.
1970. Productivity of harvesting machines designed for thinning: estimation by simulation. For. Manage. Res. Serv. Inst., Ottawa, Ontario, Inf. Rep. FMR-X-25. 29 p.

With the model annotated in Newnham (1968), the "parameters describing the B-105 Feller-Processor and its method of operation, have been tested over a range of values in order to estimate the potential productivity of the machine and to suggest areas in which its design could be improved." Felling and extraction accounted for 90 percent of the operation time, and reductions in this operation by redesign could save as much as 36.9 percent. The report represents the attainment of one of the author's objectives stated in Newnham (1967a).

Newnham, R. M.
1971. CANLOG—The new CFS harvesting machine simulator. Pulp Pap. Mag. of Can. 72(3):107-112.

CANLOG is designed to remove operational restrictions of Newham's previously designed harvesting machine simulators. The new model can account for an asymmetrical sweep of the felling boom, have cut trees swung to a point other than the rear of the machine, have the operator's cab or the processing unit restrict the swing of the boom, and have a processing method different from the one conceived for the thinning model.

The paper reports on the test of six types of harvesting machines in four test stands. The machines range from a full tree feller-buncher to a shortwood thinning feller-delimber-buncher. The stands are three natural stands of 1,436; 2,063; and 3,602 ft^3 per acre and one 8 ft x 8 ft plantation of 3,016 ft^3 per acre.

Newnham, R. M.
1972. Simulation of machines for the continuous felling of trees. For. Manage. Res. and Serv. Inst., Ottawa, Ontario, Inf. Rep. FMR-X-46. 22 p.

The model simulates the mowing down of small trees in dense stands by the uninterrupted forward movement of a harvesting machine. The object of the simulation is to study the forces present and the blade configuration of the harvester.

Rogers, Nelson, K.
1972. Uses of computer simulation techniques to help solve pulpwood harvesting and transportation problems. TAPPI 55(5):772-776.

A research program at Georgia Tech to study the systems components of the harvesting and transportation of pulpwood resulted in the construction of several simulation models as tools for analysis. Models addressing "long-range forecasting, organization and communications design, variation of production alternatives and sequences, management of resources under various allocation policies, testing machinery design options, and the evaluation of financial policies" are discussed. (Two models, Stark's "simulation model for the common harvesting systems of the southern pine region", and Bertils' "GPSS II model to evaluate terrain capabilities of typical pulpwood harvesting vehicles" are discussed elsewhere in the report.)

Santesson, Mona, and Sven Sjunnesson.
1972. Simulation model for thinning

machines. Inst. Skogsteknik, Res. Notes, Nr. 49.

The model described is a modification of a thinning systems simulation model (Newnham, Sjunnesson 1969). Programming has been simplified, and a thinning machine with bouquet-handling capabilities has been added. The bouquet-handling machine was modeled and outproduced the single-felling-head machines on all types of terrain.

Woodland, C.
1970. An application of systems simulation to the economic analysis of logging systems. Pulp Pap. Mag. of Can. 69(3):73-76.

This model, developed at the Spruce Falls Power and Paper Company Ltd., is a FORTRAN decision model that provides for the analysis and evaluation of new logging systems and equipment. The model is not a true simulation because it does not involve random sampling. It does, however, generate many different possible combinations and by relating each combination to some final cost criterion allows comparisons of relative profitability for different combinations.

The model essentially is an evaluation of a decision tree for many possible logging alternatives, and performs two related functions: 1) generates answers to "what if" questions by producing the effect on a cost criterion when values of key variables are changed, and 2) produces an expected total capital expenditure and expected operating cost per cord for each harvesting configuration.

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GOULET, DANIEL V., DONALD L. SIROIS, AND RONALD H. IFF.

1979. A survey of timber harvesting simulation models for use in the South. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. SO-25, 15 p. South. For. Exp. Stn., New Orleans, La.

Reviews literature about nine forest harvesting simulation models with potential for simulating southern operations. From the nine, five appear useful enough to warrant further analysis. An annotated bibliography of associated forest harvesting simulation literature is appended.

Additional keywords: simulation, logging, computer models, forest harvesting, survey, planning.