COSTING FOREST RESIDUE RECOVERY THROUGH SIMULATION

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ABSTRACT

The search for alternative energy sources has renewed interest in the energy potential of wood. Supplies of wood residue seem to be a likely source of material and the greatest volumes of residue are located in the forest. Methods are needed to more economically recover this residue. Traditional logging methods have been used but are too expensive. SAPLØS (Simulation APplied to LOgging Systems) is a model designed to simulate a variety of logging systems. It is used in this analysis to simulate alternative methods of residue recovery. Three case studies are developed and described in terms of model modifications. The first involves whole tree chipping of a stand. The second allows for recovery of sawlogs and subsequent chipping of the residue. The third simulates field operation of a pelletizing process that converts chips to a more dense and dry fuel pellet.

INTRODUCTION

Increasing demands for energy and dwindling supplies of traditional fuels have stimulated the search for economical alternatives to fossil fuels. One of the alternatives being considered as renewable is wood fiber. Wood supplied a significant percentage of this country's energy through the nineteenth century. It is still used as a fuel in the forest products industry, a use that has increased significantly in the past five years. The primary source of wood fuel has been unused mill wood and bark residues. This is material that is not utilized in the manufacture of lumber or one of the other wood products. The material is on site and is readily available in quantity, but volumes of unused material are rapidly decreasing. An even larger volume of material is available in the forest from the residual left after logging, trees that have died of natural causes, and the timber in low value forest stands.

Estimates of the volume of underutilized forest material vary but in the United States could be as high as nine billion cubic feet (8). The deterrent to greater utilization of this volume of wood fiber is economic. The cost of delivering this scattered, non-uniform material to a processing point can often exceed its current fuel value. Current estimates of delivery cost are based on the costs of traditional logging equipment and production rates developed for relatively uniform sized logs. Since the optimal system for recovering forest residue may not involve either, a method is needed to accurately predict delivery costs and to test alternate equipment combinations and alternate system layouts.

A simulation model is available that can be modified to provide a tool for this testing. The model is designed to simulate a variety of logging systems and their physical layout. With slight modification the model can handle a variety of forest residue recovery alternatives.

The basic simulation model will be described here along with the changes needed to simulate three methods of residue recovery. Results of all case studies were not available at the time of publication submittal but will be presented and compared at the winter computer simulation conference.

The first case will involve chipping of the whole tree for use as wood fuel. No attempt will be made to recover logs for lumber production. The second case will involve recovery of sawlogs and subsequent chipping of the residual material created by tops and limbs. Wood fiber that is used for fuel is sometimes subjected to a pre-combustion process that dries the wood fiber and makes it more suitable for burning. The third case will investigate the feasibility of taking some of this pre-combustion process closer to the forest operations.

COMPONENTS OF LOGGING SYSTEMS

Logging operations consist of five principal components: felling, bucking, skidding, loading, and hauling. Some operations also include modifications of these components. Felling usually involves cutting, limbing and topping of the tree. In whole tree operations limbing and topping are not performed. Bucking will result in a long log being cut into shorter, more manageable pieces. It is sometimes accomplished by the person doing the felling, sometimes by a separate individual at the loading area, and is sometimes not part of the system.

Skidding involves transportaiton of the log or whole tree from the felling area to the loading area. It can be accomplished by crawler tractors, four wheel drive machines called wheeled skidders, or a variety of cable winches that drag or fly the log using long wire cables and winching yarders. The skidding operation is sometimes divided into two segments: one called prebunching that transports logs from the tree stump to a skid trail, and a second which uses faster machines to transport bunched logs from the side of a trail to the loading area.

As the name implies, loading consists of loading decked logs on long distance transport vehicles. In chipping operations, the logs are chipped and loaded in one operation. Hauling is generally accomplished by truck and trailer. In some systems, especially chipping operations, the trailers are moved to an intermediate docking point by a truck and picked up at the prehaul dock by highway trucks.

Residue recovery operations will usually include the five components just described. However, some subtle, yet important changes are required to accurately simulate residue recovery. Felling production rates will include only the time for cutting a tree. Production rates for skidding must be structured for the skidding of whole trees rather than logs. Bucking logic must be established to determine the portion of the tree, if any, that will go into sawlogs and must reflect the increased time for the bucker to limb the tree. If, as described here, some of the pre-combustion process is to take place at the prehaul dock, then the logic for operations at the prehaul dock must be revised.

A logging system will usually involve simultaneous operations in the five components. The cycle within each component consists of a variety of activities that are started and stopped by discrete events at a maximum five locations in the harvest tract. Logging and residue recovery can be adequately simulated through discrete-event simulation, but the model must be capable of handling a variety of equipment combinations, terrain characteristics, and system layouts.

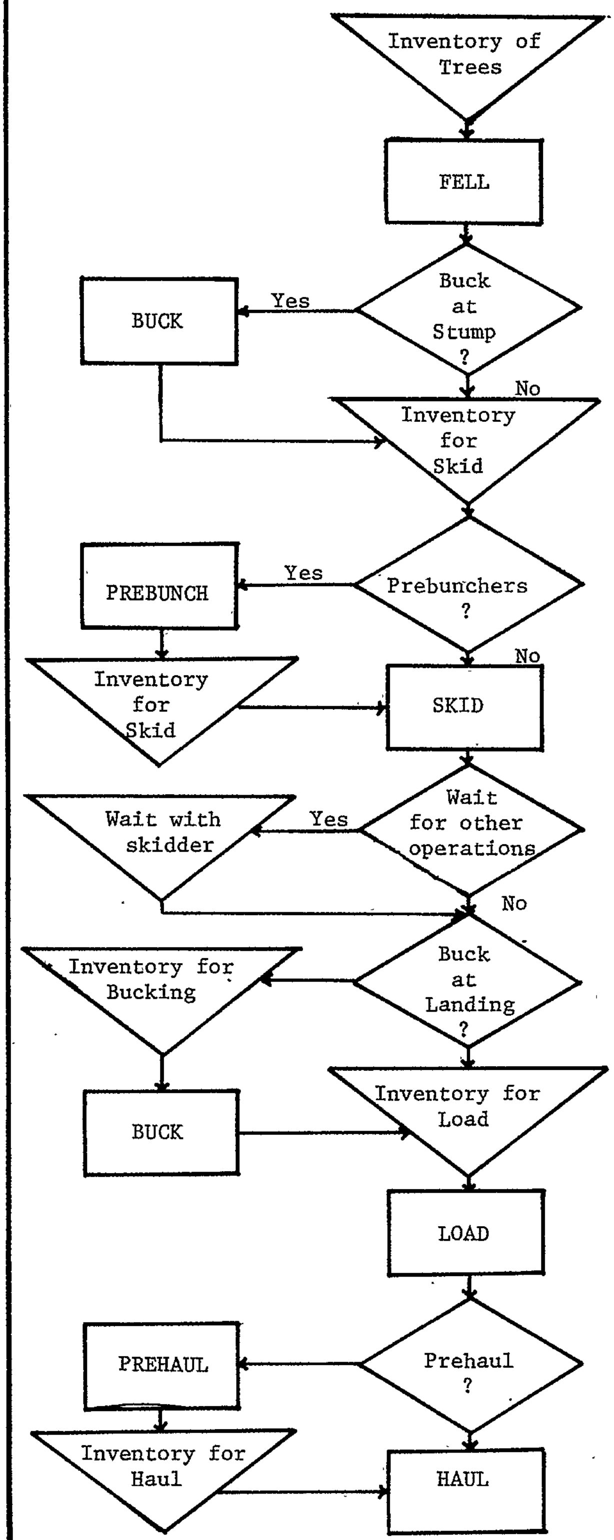
LOGIC OF SAPLØS

SAPLØS (Simulation APplied to LOgging Systems) was developed at the engineering work unit of the U.S. Forest Service in Morgantown, West Virginia. It is a discrete-event simulation model written in the GASP IV simulation language. It was originally written in GASP II and later converted to GASP IV to facilitate its inclusion in a model used to simulate both logging costs and the environmental effects of logging. The model has been used in a variety of case studies of traditional logging (2,9) and in a case study of whole tree chipping (10).

SAPLØS models events at five critical locations in a harvest tract: stump, skid trail, landing, prehaul dock, and mill. These locations mark an interaction between two or more components of the logging system. This can be best illustrated by following the flow of logs through the system as shown in Figure 1. Interaction between felling

FIGURE 1:

Flow of Logs Through SAPLØS Model



Using a 66% conversion efficiency, the as fired value of the wood fuel is $2.29/10^6 BTU. Assuming an 80% conversion efficiency for oil, gas, and coal, their as fired value becomes $4.08, $2.73, and $1.91 per million BTU, respectively.

Another stated drawback to the use of wood fiber for fuel is the demand for its use in the manufacture of wood products. The current price paid by the pulpwood industry for whole tree chips is about $10.40/green ton (1). At 55 green pounds per cubic foot (13) this equates to $.286 per cubic foot and a fuel equivalent price of $1.16/10^6 BTU. In this case the whole tree chips appear to have greater value as fuel than for pulp production.

TABLE 1

Results of Basic Case

Volume Produced:	36,866 cubic feet
Trees Processed	1616
Hours of Production:	116.6
System Cost:	$.386 / cubic foot

	Fell	Skid	Chip	Hauling Shtle	Hauling Hghwy
Percent Time Productive	59.0%	85.6%	10.5%	21.3%	36.5%
Percent Time in System Delay	0.0%	2.6%	82.2%	72.2%	54.9%
Percent Time in Breakdown, Maintenance, Personal Delay	41.0%	11.8%	7.3%	6.5%	8.6%
Production Rate cu.ft/hr	361	357	353	352	314
Cost in $/cu.ft.	.0134	.1870	.0895	.0177	.0788

CASE TWO: SEQUENTIAL RECOVERY OF SAWLOGS AND RESIDUE

The potential loss in revenue that can result from chipping the whole tree without regard for sawlog recovery is investigated in this case. Whole trees will be delivered to the landing and the bucker will limb, top, and buck the trees. Sawlogs will be loaded and hauled to a mill and the residue piled at the landing for chipping. This system requires enough landing area for sawlog decks, skidding and chipping operations, and the piles of residue that will be generated. After completion of sawlog recovery, a chipper and trucks will be brought into the area to chip and haul the residue for use as a fuel.

Several model modifications are needed to simulate this system. The first requirement is for logic in the bucking subsystem to determine the portion of the tree cut into sawlogs and the volume added as residue. Adjustment of bucking logic will also necessitate an adjustment to bucking time.

Simulation of this case will be accomplished through two runs of the model. The first run, employing a feller, bucker, running skyline, loader, and trucks, will determine the cost and time required for sawlog recovery. Ten residue volumes, one for each landing, will be generated in the bucking subsystem, stored in an output array, and used as input to the second run. Model modifications are needed to handle storage and retrieval of this data. The second run will involve just a chipper, shuttle truck, and highway trucks. Model modifications that allow felling and skidding to be bypassed in a simulation run are also needed.

The cost determined in the second run will reflect only the cost of chipping and hauling. The cost of delivering the residue to the landing will have been borne by the sawlog operation. This cost discrepancy can be handled two ways: the skidding cost from the first run can be divided to reflect the portion caused by residue delivery or the cost of skidding the residue can be assumed to be part of the sawlog operation and charged as a cost of slash disposal. The first method requires an additional test run of the simulation so that the cost of skidding logs without branches and tops can be determined.

Several variations of this case study can also be tested. Chipper size can be varied. The logic used in bucking to determine the part of a tree that makes a sawlog can also be changed. Finally, production rates of equipment can be varied to reflect increased or decreased interference at the landing.

Simulation results were not available for this case at the time of publication. However, they would be compared to the results of the first case by determining the net revenue obtained from the products. Revenue will be based upon a sawlog price of $70/thousand board feet (Doyle Scale) (1) and a whole tree chip price equal to its delivery cost.

CASE THREE: PRE-COMBUSTION PROCESSING AT PREHAUL DOCK

Chipping converts non-uniform tree tops and limbs that make up residue into a uniform, transportable product. Although they are uniform, the chips usually contain a large quantity of moisture. Up to fifty percent of the load in any chip van could be water. The whole tree chipper blows chips into the van, but no attempt is made to further compact the chips. High moisture content and lack and either prebunching or skidding will occur at the stump. Prebunch-skidding interaction takes place at the skid trail. Bucking, skidding, loading, and hauling all interact at the landing. The prehaul dock is the meeting point for shuttle and highway trucks. System delays will occur whenever the inventory points shown in Figure 1 fall to zero or whenever they reach such a high level that they block subsequent entry to a work area.

The beginning and ending of activities at each of these locations was modeled through arrival and end-of-service events. Following the GASP IV format two event subroutines were written for three of the critical locations. At the mill and prehaul dock both arrivals and ends-of-service were processed in the same subroutine. An additional subroutine was written to process events at the end of each working day and schedule initial events for the next day. The event subroutines written for the GASP IV model include the following:

- ARTRE - Arrival of feller or skidder at the tree stump
- ESTRE - End of felling or skidder hooking at tree stump
- ARSRD - Arrival of skidder or prebuncher at the skid road
- ESSRD - End of unhooking or hooking at the skid road
- ARRVL - Arrival of skidder, bucker, loader or truck at the landing
- ENDSV - End of landing activities for skidder, bucker, loader or truck
- ARDOK - Arrival and end of service of trucks at prehaul dock
- ARMIL - Arrival and end of service of trucks at processing point
- ENDAY - Process events at the end of each working day

The general logic for equipment used in the various components is similar. In arrival subroutines checks are made for delays caused by lack of room or wood, and if there are no delays, an end-of-service is scheduled. Statistics are also collected on travel time. Production statistics and inventories are updated in an end-of-service event, the next arrival is scheduled and checks are made for delayed equipment. Specific logic for the various machine types differ at each location.

The model described can handle a variety of logging systems and, with some modification, a variety of residue recovery operations. It can be used to simulate manual or mechanical felling; cable or ground skidding; single or multiple landings; sawlog, pulpwood, or whole-tree chipping systems; and prebunch and prehaul system variations. The residue recovery cases tested here will be described in terms of model modifications required, results expected, and additional variations that could be conducted within each case.

CASE STUDIES

CASE ONE: WHOLE TREE CHIPPING

The first case involves chipping of the whole tree. The entire stand will be converted to a fuel product with no effort to recover sawlogs. Although this process is efficient and results in maximum utilization of the stand, it does not always result in maximum return from the timber. Sawlogs are often more valuable than wood fiber that is converted to chips. Whole tree chipping will usually be used on low value hardwood stands where few good sawlogs exist. It is used as the base case here since it will result in maximum fiber recovery.

This type operation is currently used in some areas to produce pulpwood chip and will not require modification of the simulation model. The particular operation simulated here is located in the Appalacian mountains and because of the steep terrain will utilize a cable system known as the running skyline. Running skylines are efficient and can transport logs uphill and downhill, but they are also quite expensive. The machine used in this case requires capital outlay of $300,000 and four people on the crew. The skyline will be coupled with one feller, a whole tree chipper, one shuttle truck, and two highway trucks.

The timber stand is composed of low value hardwoods of mixed species. Trees average 11.6 inches in diameter and 35.4 feet in height. The test tract is approximately 4 acres, requiring 10 landings at a spacing of 200 feet. The stand is located 55 miles from the processing point. Harvesting of this tract required 117 hours and the system delivered wood to the processing point at a cost of $.386 per cubic foot. Detailed results of this case are presented in Table 1.

As can be seen, the chipper encountered significant system delays. These were in a category called "waiting for wood". It indicates that chipper productive capacity exceeds that of the skyline. These results are not untypical of skyline-chipping systems since chipping capacity generally exceeds that of a single skidding machine. In this case it is not possible to add an additional skidding unit because of space limitations. One alternative for decreasing cost would be use of a lower capacity chipper. If chipping capacity is fixed, the only opportunity for cost improvement appears to be in the trucking segment. Since highway trucks also incur large delays, it may be possible to drop one highway truck from the system.

The system cost can be converted to an equivalent fuel cost in dollars per million BTU to allow comparison to the cost of conventional fuels. The conversion will be made using the following assumptions: higher heat value of 8500 BTU/dry pound, weight of 30 dry pounds per cubic foot, moisture content of 50%, and conversion efficiency of 66% (4,13). Using the higher heat value of wood the delivery cost converts to an equivalent fuel value of $\$1.51/10^6$ BTU. This compares to conventional fuel costs of $\$3.26/10^6$ BTU for oil, $\$2.18/10^6$ BTU for gas, and $\$1.53/10^6$ BTU for coal (15).

of compaction increase the hauling cost and high moisture content decreases chip value when the chips are used in a combustion process.

If the product transported from the woods were more dense and dry, residue recovery might be more economically attractive. Most of the systems currently used to produce a densified product are too large and heavy to be taken to log landings. The frequent moves required in woods operations currently make their use unrealistic. It may be possible, however, to mount the system on a series of tractor trailers, park them at a large area close to the woods, and shuttle chipped material to the setup. The system will not be portable in the same sense as a whole tree chipper, but could be moved every 6 months to a year following the harvest of a large area. A decision to use the system will involve a tradeoff between the additional investment in equipment and processing cost and the increased revenue from the cost savings in hauling and the increased value of the fuel product.

Several methods are currently available to densify the wood fiber and improve its combustion properties. These include various types of pelletizing processes (3,5), equipment to compact residue (6), and a variety of systems for gasifying or liquifying the material (7,12). Pelletizing systems work on the same principle as equipment used in agriculture to produce feed pellets. Available systems vary from those which simply compress the material to those which use heat and pressure to change the chemical structure of the material. Compaction systems produce a compact product but do not necessarily achieve the low moisture content present in pelletized material. Gasification or liquification is technically feasible but most systems are still in the experimental stage.

None of the three options have been constructed on the semi-portable trailer systems envisioned here. Since pelletizing systems are receiving increased interest and seem to be more technically advanced, they will be tested in this case study.

Densification will be simulated by introducing it as a process at the prehaul dock. The process is described in terms of three functions; unloading, processing, and loading. Loading can be achieved by one of two alternatives: loading vans as they arrive or carrying an inventory of extra chip vans for direct loading from the process system. Delays will occur if the process runs short of wood, if there are no processed pellets for loading, or in the second loading alternative, if there are no chip vans available to load. Statistics will be collected on the operating and delay time of the system. There is no provision in SAPLØS to account for the cost of the pre-combustion system so it will be added to the total system cost calculated by SAPLØS after completion of the simulation run. The equipment used for the pre-combustion process will cost about $650,000 installed on flat-bed trailers. Pellets produced from the process have a density of 35 pounds per cubic foot, moisture content of 14%, and an as-fired fuel value of 7200 BTU per pound (14).
Several variations can be simulated within this case. Design of the pre-combustion system can be accomplished by changing loader, unloader, and process speeds. The alternate methods of loading, a separate loader versus extra chip vans, can be tested. Finally, the distance from the woods operation to the prehaul dock can be varied to determine the limits of economical operation.

Results of this case must be compared to results of the first case on the basis of cost and the fuel value of the product. Material produced in the first case was assumed to have a moisture content of 50% and a conversion efficiency of 66%. As just noted, the pellets will have a moisture content of 14% and a conversion efficiency of 85%.

Once delivery costs for both cases are converted to a fuel equivalent cost they must be divided by their respective conversion efficiencies to determine as fired fuel costs. This comparison accounts for the difference in fuel value, but does not consider the advantage of firing pellets which have a uniform size and moisture content over firing chips which vary in size and moisture content.

Comparison of this case with the first case will determine whether the increased fuel value of the pellets and decreased trucking costs per cubic foot offset the extra cost of processing.

SUMMARY

Simulation results of the two variations were not available at the time of submission of the publication. However, the description presented here does point to the value of simulation in analyzing the options available in residue recovery operations. Since interest in achieving greater utilization of this potentially valuable residue will increase, simulation can be the tool used to refine and test the systems that will be designed to accomplish this task. This testing can be achieved with a minimum of expensive, initial field testing.

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