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A SIMULATION MODEL FOR THE COMMON
PULPWOOD HARVESTING SYSTEMS OF THE
SOUTHERN PINE REGION

A THESIS
Presented to
The Faculty of the Graduate Division
by
James J. Stark

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A SIMULATION MODEL FOR THE COMMON
PULPWOOD HARVESTING SYSTEMS OF THE
SOUTHERN PINE REGION

Approved:

Chairman

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SUMMARY

This work was undertaken in conjunction with a research grant awarded to the Georgia Institute of Technology, School of Industrial Engineering, by the Southern Executives Association to study the systems aspects of pulpwood harvesting. The purpose of this thesis is to form a basis for further research by Industrial Engineers in the problems associated with pulpwood harvesting in the 12 southeastern states. The thesis is primarily concerned with analysis and modeling of the common 5'3" pulpwood harvesting operations of the Southeast and the programming of the model in General Purpose System Simulator language (GPSS-II) for system simulation on a Univac U-1108 digital computer. The simulation model considers 12 basic pulpwood harvesting operations and allows for the assembly of any one of 28 possible, realistic systems. There are 19 variables which require data probability distributions and 15 parameters which can be set. A computer software problem allowed for only a single harvesting system to be simulated; however, those results correlated with the real world system. Further research is expected when the computer software problem is solved.

The constraints presently placed on pulpwood production are defined and quantified. Harvesting constraints
discussed include the pulpwood harvesting evolution, pulpwood measure and specifications, and industry trends and pressures.

The method of attack was that of Systems Analysis which consists of eight distinct parts: system definition, reticulation, abstraction, identification, measurement, solution, optimization, and validation.
CHAPTER I

INTRODUCTION

Background

The record of the pulpwood industry in the South has been one of exceptional growth over the past several decades. In 1920, there were 24 pulp mills operating in the South with an average mill production capacity of 41 tons of pulp per day (61). In 1966, 87 mills were in operation and average mill capacity had climbed to approximately 744 tons per day (52). In 1920 the South's share had been only six per cent of the nation's total pulp production, but by the end of 1966 the combined capacity of southern pulp mills represented fifty-eight per cent of the total national production (52). These statistics clearly indicate that the majority of the national pulpwood industry has shifted to the South.

While the number of pulp mills in the South and their capacity is known exactly, there are only rough approximations of the number of independent pulpwood producers in the entire Southeast. Today's partially mechanized,
full-time producers can consistently produce 100 cords of pulpwood per week. If all producers could harvest just 4000 cords per year (worked 40 of 52 weeks) it would have only required 8,250 producers to supply the 33 million cords harvested in 1966. Yet one company paid nearly 10,000 different producers in the year 1966. This clearly shows that even with present methods and machinery, the industry needs could easily be met with the available labor force if the present woods workers were full-time workers. Unfortunately, pulpwood harvesting is a seasonal or part-time occupation of the rural farmer. From the large number of producers paid and the small number of producers actually required, the small scale of operation of the typical supplier is apparent.

The objective sought by the pulp mills is an efficient, reliable, year-round pulpwood source. To obtain this objective, the industry seeks to grow more timber, harvest it more economically, and obtain better utilization from each tree (11). With respect to the harvesting goal, the industry is now seriously searching for feasible methods which will increase the productivity of the producers in order to cope with the increasing demand for pulpwood and the decline of the labor supply traditionally used in woods work (11, 22).

In conjunction with this industry objective, at the start of the summer of 1967 a group of southern pulp mill
executives, called the Southern Executives Association (S.E.A.) awarded a research grant to the Georgia Institute of Technology, School of Industrial Engineering, to study the "Systems Aspect of Harvesting and Transportation of Pulpwood." The objective of the research program is to structure a systems model sufficient to validly represent the significant characteristics and constraints on present systems, and as the systems may appear up to the year 2000. This is the first thesis of the program and as such it endeavors to lay the basic foundation concerning common, present day harvesting systems. (See Appendix I concerning the full objectives, scope and method of approach to be used over the research program.)

It is the objective of this thesis to form the groundwork necessary for further research and study in the area of pulpwood harvesting and transportation, i.e., to study the basic systems commonly used by the majority of pulpwood producers. In order to achieve this objective the following specific goals were attained: (1) characteristics and constraints presently imposed on the common systems of pulpwood harvesting were defined and quantified, (2) three basic systems were defined, and (3) a general simulation program was developed which is representative of the common 5'3" pulpwood harvesting methods. The objective of the simulation program was limited to construction and validation of a basic program for the three systems defined. It is
expected that those who continue the research program will be interested in making system comparisons and response studies of parameter settings.

Scope of Research

This research is directed toward the common, existing facilities now utilized in the production of 5'3" pulpwood. However, any organization concerned with pulpwood harvesting might find the approach and methodology useful. For example, in the study of long-wood pulpwood harvesting systems many of the same basic principles of operation are found and it is expected that these results would be useful in this area.

The scope of this research is constrained to 5'3" pulpwood harvesting in the South. With considerably more research and a general reprogramming of the model, this approach could be utilized to study many systems for the harvesting of forest products.

Approach

The approach used in this study is that of systems analysis. Dr. Hanken, in his course in Systems Engineering, states that systems analysis methodology consists of eight distinct parts. The parts are: (1) system definition, (2) reticulation, (3) abstraction, (4) identification, (5) measurement, (6) solution, (7) optimization, and (8) validation. This basic methodology was adopted for this study
for two reasons. First, the pulpwood harvesting procedure is amenable to this approach and second, the methodology allows for an orderly construction of the simulation model. The details of this method are outlined in Chapter IV--Procedure.
CHAPTER II

LITERATURE SURVEY

Pulpwood Harvesting Literature

Pressures on the Industry

Today the pulp and paper industry is expanding to meet the constantly increasing demand for pulp products (8, 39, 58). The increased number of pulp mills and mill capacity in the South is stated on page one of this thesis. However, the increasing demand for pulp products can most easily be seen from the rise in per capita consumption of ordinary paper. In 1920, the per capita consumption was 90 lbs. In 1965 this had increased to 495 lbs. (37) and the first estimates of 1967 per capita consumption of paper state that there is now over 500 lbs. of paper per year per person used in the United States. In 1961, a consumption of 550 lbs. per person was predicted for 1975 (44, 58).

Concurrent with the increased demand for pulp products is the well established decline in the rural, Southern, unskilled labor which has traditionally been used for pulpwood harvesting (11, 22). This declining labor pool is assumed to have reduced the number of part-time producers formerly relied on to meet demand. The declining labor supply, the booming economy of the sixties, and rising minimum wage are the major factors which have contributed to
the pressure on the pulp-using industries* to find a con-
sistent economical supply of pulpwood.

Industry Research Efforts

Faced with increasing demand and decreasing supply
of labor for harvesting, the industry is now willing to
pay for research—both basic and applied—from universities
and private research institutes in areas which will be of
benefit to the entire industry. At present here in the
South, the industry is sponsoring research projects at Georgia
Institute of Technology and at Auburn University in the
area of pulpwood harvesting. Across the South, other uni-
versities** having forestry schools are working on research
projects in other areas for the industry. The American
Pulpwood Association has recently established a Pulpwood
Harvesting Research Program in Atlanta, Ga. The Associa-
tion is presently concluding a three year survey of southern
pulpwood producers. The survey was designed to gather data
on all phases of present pulpwood systems. In order to
efficiently utilize this data, Honeywell Corporation is
working on a computerized storage and retrieval system.
The John Deere Company has been retained by the industry

*Pulp-using industries are hereafter referred to as
"the industry."

**University of Georgia, North Carolina State, Louis-
iana State University, Clemson University, Florida State
University, and Auburn University.
to do research on forestry machinery.

This willingness of the industry to sponsor research has not always existed. From 1960 to 1963 a coalition of companies sponsored a major research project by Battelle Memorial Institute (19, 20, 21). The results were a series of twelve reports utilizing various techniques to study pulpwood harvesting. These results were considered proprietary information until the middle of 1967. While Battelle's research did produce some recommendations which could be applied to the industry successfully, no direct change can be seen to have been brought about. However, indirectly, the fact that scientific research could be applied to pulpwood harvesting has perhaps assisted in the present willingness of the industry to sponsor research.

**Pulpwood Harvesting Machinery**

There has been a veritable flood of papers discussing concepts and aspects of the new ideas and new machinery being developed for pulpwood harvesting during the past six years. While this literature is relevant to the objectives of this study, it is also rather extensive and we are forced to briefly cite only a few representative papers (6, 24, 51, 59, 60). The literature on mechanical harvesters is almost exclusively from the United States, Canada, Sweden, and the Soviet Union. However, it has only been in the past two years that harvesting machines have emerged from prototype to production. The literature on harvesting
machinery predominantly concerns long-length and whole-tree logging (33). This follows, as machinery can efficiently handle long-length wood. Virtually nothing is written concerning mechanical shortwood harvesting systems. The exception to this are the articles on the Busch Combine harvester, designed here in the South to be compatible with existing mill requirements for shortwood (44, 45).

From the literature on logging machines several generalizations can be made. First, the only standard piece of machinery here in the South (and generally world-wide since about 1965) (26, 38) is the chain saw used for felling. While the power saw is also used for limbing in the South, it has been shown that a hand bow-saw is more productive in species and stands found in the northern, central states region (14). Secondly, due to climate and terrain differences, no one piece of machinery will be applicable to all pulpwood harvesting (6, 50). This applies here in the South as there are three basic terrains found in this area alone: the coastal plains, the Appalachian uplands, and the Piedmont Plateau. Third, there is a tremendous potential market for harvesting machinery. The manufacturer who can produce an efficient machine, capable of operating under widely varying conditions, can expect to receive great financial reward. However, the amount of capital necessary to own and operate present harvesting machinery portends a major procurement system change for the South.
While the major emphasis has been on the building of mechanical harvesters in the United States and Soviet Union, in Great Britain and Soviet Latvia the emphasis appears to be toward the development of a machine to economically harvest the thinnings from plantations. This area is missing from American literature as the greater proportion of American pine plantations are not yet near enough to the stage for thinning. This is an area of research which cannot be put off too long for the pulpwood industry in the South.

New models of de-barking machines are being produced. Studies have been made on the commercially available machines regarding their economics and quality of work (28, 48, 54). Basic research has been started on measuring the bond strength between the bark and wood in Canada. Chemical barking of the standing tree has yielded very disappointing results in British research (34).

Chipping in the forest shows increasing interest in the United States, Soviet Union, Poland, Germany and Sweden. These papers (2, 29, 32) contain studies on chipping machinery, work organization, economics, etc. Canada has not yet released their economic feasibility studies of chip pipelines, but there are several organizations studying this approach to transportation (33).

**Industrial Engineering Work Study**

In a 1967 world literature survey (38), there were 44 reports of research in the area of Work Study. Partic-
ular note was made that the recent literature shows a defi-
nite move away from stop-watch methods in favor of work-
sampling or activity-sampling techniques. Further, of the
papers cited in the survey, not one was of American origin.
While the studies of skidder operations, such as (12), belong
in this category of literature, there is a major deficiency
in Southern pulpwood harvesting literature with respect to
such areas as those dealing with comparisons of methodology
and productivity for elements of operations and psychological
and physiological studies of the human factors. Canada
has a variety of methods to calculate payment for woods
workers, with most methods using an incentive plan; however,
similar research on Southern woods labor problems is nearly
non-existent.

Pulpwood Standards

A basic lack of standards is also apparent in the
industry. Previously the lack of standard machinery was
cited. Together with the variety of machines is the variety
of methods of harvesting pulpwood, even among those systems
using similar machines. This fact is demonstrated in Figure
2 which shows the possible combinations of basic harvesting
operations commonly found here in the South.

Chapter III discusses the various pulpwood measures
of weight and volume. An understanding of pulpwood measure
is essential for reading the literature. Canada uses a
measure called the cunit or C-unit. Here in the South
pulpwood is commonly measured by the cord; however, the term unit is also extensively used in the literature. Each of these terms is defined by volume and by weight measure with the inevitable result of variation as to exactly what is meant (3, 5, 42). Associated with this, there is a lack of standards on what constitutes acceptable "roundwood" (1, 14, 53). A list of general criteria commonly used in company wood specifications has been formulated in Chapter III.

Simulation Literature

History of Simulation

Simulation has a long and honorable history. This was the method employed to obtain the celestial navigation tables needed for world exploration and establishment of international trade. For navigation, the value was so great that men spent their lifetime compiling by hand computation the future positions of the moon, planets, and stars (15). This laborious process was the only alternative because an analytical solution to the multi-body problem could not be found.

Until the electronic computer became available, the cost of simulation rendered it economically unfeasible, therefore, little was known of its power or potential. Because simulation was unknown it was not even attempted for those situations which might have been economically justifiable.
Analog and digital computers arrived as engineers became involved in systems of such complexity that they could not be simplified to obtain analytical solutions. The demand for simulation has risen since 1950 as the cost of the computer has decreased. Perhaps the largest single item contributing to the rapid rise of simulation was its use in post World War II in the solution of atomic energy problems (21, 47).

**Literature Partition**

The literature describing simulation experiments can be partitioned according to the kind of system measurement used. Military simulation experiments tend to measure a systems response to all possible situations (13); research simulations tend to measure systems response to a specific set of initial conditions (10, 36). There appears to be a definite lack of literature on measurement of response to system initial conditions. It is felt that this is an indication of its specialized nature, not its worth (13). In this study, the simulation program of the specialized topic of pulpwood harvesting in the South, the concept of measurement of system response to initial conditions is expanded. The expansion is accomplished through the use of user designed distributions describing the initial conditions from which random samples are taken and tested for their effect on the system.
Definition of Simulation

In the past the term simulation has had many meanings. Everyone who has had some influence on its development has applied his own definition. This has resulted in a class of vague, often conflicting, ideas about just what simulation is and what it encompasses. C.W. Churchman has set down two somewhat philosophical definitions. However, Thomas H. Naylor gives a definition that involves the common concepts of the simulation technique:

Simulation is a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behavior of a business or economic system (or some component thereof) over extended periods of real time (35, p. 3).

The concept of model building is stressed by Dimitris M. Chorafas in his definition:

Simulation involves the construction of a working mathematical or physical model presenting similarity of properties of relationships with the natural or technological system under study (9, p. 9).

Martin Shubik gives the advantages and purposes of simulation in a concise form in his definition:

A simulation of a system or an organism is the operation of a model or simulator which is a representation of the system or organism. The model is amenable to manipulations which would be impossible, too expensive or impractical to perform on the entity it portrays. The operation of the model can be studied and, from it, properties concerning the behavior of the actual system or its subsystems can be inferred (49, p. 199).

P.J. Kiviat (27) simplifies the definition by stating
that "Simulation is the use of a numerical model to study the behavior of a system as it operates over time."

Note the use of the word "study." When a simulation model is given a set of input parameters and an initial system state, it is "run" to deduce subsequent system states and estimate measures of system performance. Different parameter settings produce different system responses. These responses are studied to determine the set of parameter values that in some sense optimizes system performance. A simulation model programmed in GPSS-II computer language is used in an experimental manner; it does not find or seek optimal system parameter settings by itself. This is the conceptual framework for simulation in this thesis.

**Simulation Program Languages**

For this research a computer was available, and, since the computation time by hand appeared to be excessive, it was decided to program the problem for machine solution. The programming time, even with a general purpose language, could not compare with the time required to solve even a very small portion of the experiments possible if they were done by hand.

The selection of a computer language for programming the simulation was dependent on the capabilities of available hardware. Several special purpose computer languages have been developed which make simulation programming easier and more comprehensive. Two of the most notable of these
are: SIMSCRIPT, a product of the Rand Corporation, and General Purpose Systems Simulator (GPSS-II), developed by IBM Corporation. A number of other languages have been written but they are primarily for particular types of problems and do not have the general applicability of SIMSCRIPT and GPSS-II.

GPSS and SIMSCRIPT facilitate the preparation of simulation programs in two ways:

1. They provide a convenient set of concepts for translating the model from an ordinary word description to a more rigorous and complete description from which it is easier to write a computer program. This set of concepts is termed the "world view" of the language.

2. They provide a language which is particularly suited for transforming the above description of the model into a computer program.

Both languages are predicated on the assumption that computer time is inexpensive relative to the cost of a programmer. As such, they substantially reduce the programming effort required by shifting much of the translating task to the computer (17, p. 3).

Both languages offer the advantage of shorter programming times when compared to a general purpose language such as FORTRAN or ALGOL. Since GPSS-II was available and there initially was a programmer at the Rich Computer Center of Georgia Institute of Technology trained in the language, GPSS-II was chosen to model the system.

The GPSS-II programmer requires only a Reference Manual which is written specifically for the U-1108 computer by Univac Data Processing Division.
The program described herein is a general-purpose simulator designed to aid system study work. The system to be simulated must be described by the user in terms of a special block diagram. The program operates on the UNIVAC 1108 and no knowledge of the computer operation is assumed. The user need only know the rules by which the block diagrams are constructed (57, p. 3).

The details of how GPSS-II was used in the model building process is covered in Chapter IV. The programming time was lengthy since programming aid was not available when the actual program was written; however, it was considerably shorter than it would have been if a general purpose language had been used. The real time saving was in the "de-bugging" of the program after it was first written.

Technical Simulation Problems

Although simulation has many advantages, the difficulty involved in developing a model, programming the model, and utilizing the results should not be overlooked. Computer programming has proven to be the major stumbling block in many simulation attempts. This difficulty has been overcome in recent years to a large part through the development of specialized simulation languages (DYNAMO, SIMSCRIPT, SIMULA, GPSS-II, etc.).

Another problem area is that of the experimental design. Considerable effort can be expended with little result if the manner of design and the input data are poor. This was realized many years ago and popularized by the term GIGO (Garbage In-Garbage Out); however, this area is still a major pitfall (13).
One prime area of difficulty deals with statistical questions. Simply because a problem is run on a computer does not mean it is either valid or statistically significant. Fishman and Kiviat (13) raise several statistical questions which are common to all problem analyses and to model structural verification and validation as well. One question relates to sampling interval, or the choice of time between successive observations. Another question deals with method to efficiently obtain results of a desired level of reliability. This question is often discussed under "variance reduction techniques" in the literature of statistics. However, reliability estimation itself poses a statistical problem with respect to length of time to run the simulation.

Finally, in any system, there are certain key characteristics which will contribute the majority of information to be derived from the simulation (4). There are always a greater number of minor factors than it is feasible to include in the program. Thus, the number and type of characteristics to be included should be carefully selected.

By discussing these four problem areas it is not to be inferred that this is the extent of simulation problems. These areas are mentioned because of the problems posed to the author.

Forestry Simulation Literature

George H. Furnival (16), in the 1966 Forestry Symposium at Louisiana State University, stated that there are
three basic uses of the computer in forestry. These are (1) to compile statistics to describe the forest, (2) to predict change in a given forest, and (3) to aid in analysis of management alternatives. The technique of computer simulation as a forestry management tool belongs in this third class.

At present two forest simulators approach operational status. One is the Harvard Forest Simulator, developed by E.M. Gould and W.G. O'Regan in 1965 (18); the other is the University of Georgia program, FOPS, prepared by J.L. Clutter and J.H. Bamping in 1967 (10). Both simulators employ yield tables and suffer from the weaknesses recognized as inherent in yield tables. Both require that the entire stand be used as the basic unit of record keeping. While this reduces the initial computer data problem, it creates additional work in remapping of stands and keeping track of the cut by stands. However, while several authors have enumerated these basic weaknesses, none have suggested a better method (16, 40).

These simulators are receiving attention because they offer at least a partial solution to an important problem. The most elaborate forest inventory, no matter how current and detailed, can only answer the question, "What is the present forest condition?" The reply of a computer to this question, while useful, tells management only present data. These forest simulators are designed to answer the more
pointed question, "Given the present forest conditions, what will be the economic consequences of a particular management decision?" Thus, by asking the question for each possible decision, the simulator provides a means of answering the basic question, "What should be the management practices on a given forest property?" With 75 million acres of forest owned by the pulp mills of the South, this question is of great economic interest.

Although pulpwood harvesting is also a multi-million dollar industry, there are no producers with the facilities or capital to study harvesting by computer simulation. To date, the only pulpwood harvesting study utilizing simulation is by R.M. Newnham (36). This study simulates the passage of a feller-buncher type of harvesting machine through a pulpwood stand. The input parameters for the model are the stand and machine characteristics; the output gives a breakdown of harvesting time (into machine travelling time, felling and bunching time, unloading and non-productive time), the position of each sweep and the number of trees felled and their volume. An optional computer map is produced to show the spatial pattern of the trees and the harvesting pattern.

Stand characteristics (spatial distribution, log diameter distribution, stand density, and tree volume) were artificially generated or kept constant for all tests in order to eliminate costly and time-consuming field work to
gather the necessary data. The model does have some response to the presence of cull trees; however, this does present a possible conflict with one of the basic assumptions of the model. The effects of slope and microtopography were not considered in this model. As a harvesting machine simulator, the model is flexible and has produced results close to those published by manufacturers of feller-buncher harvesters.

Row (46), in 1963, developed a FORTRAN program to compute rates-of-return for complex forest-investment alternatives. This program evaluates six investment alternatives simultaneously and performs the analyses repetitively for many cost and price situations.

Palley and O'Regan (41, 43) have published two studies utilizing a computer to compare forestry sampling techniques. Chappelle (7), a forest economist, has published a FORTRAN IV program for calculating allowable cut from a stand. Hool (25) and Tse-Hao (56) are typical of the many M.S. and Ph.D. thesis and dissertations utilizing specific computer techniques to approach general forestry problems.

Thus, while the computer has been used in forestry, the particular technique of simulation and the use of a computer to aid harvesting studies is virtually non-existent. However, as research efforts increase, the use of simulation will increase. Simulation can cope with the multitude of factors involved in the harvesting or management of a large forest property with our present state of knowledge.
CHAPTER III

CHARACTERISTICS AND CONSTRAINTS

Pulpwood Specifications

The pulp mills which have entered the South in the past two decades have designed their plant equipment to handle the existing common form of the raw material. This has resulted in the placing of the largest single constraint on pulpwood harvesting, namely, the requirement for pulpwood to be in the form of a 5'3" bolt. Chips are the only other generally acceptable form of the raw material since all pulpwood is ultimately reduced to chip form.

Every mill has published a list of specifications for pulpwood which it will accept; however, the following seven specifications are representative of the industry requirements:

(1) Bolts must be at least $\frac{27}{4}$ to 47 inches in diameter inside the bark at the small end and cut to the specified length.

(2) Bolts must not exceed $\frac{13}{18}$ to 247 inches in diameter outside the bark at the large end.

(3) Wood must be straight and sound.

(4) Ends must be cut square and limbs trimmed flush.

(5) No burned or rotten wood is accepted.

(6) All nails and metal must be removed from bolts.
the raw material and therefore the present supply system.

Long-length wood and chip have been predicted as the coming form of pulpwood as far back as 1953 (31).

Volume Measure

The standard cord of wood is a rick (or stack) measuring 4 x 4 x 8 feet and containing 128 cubic feet. However, this is a measure of space occupied as it contains wood, bark, and many voids. Short cords and long cords are common variations of the standard cord and are often referred to as "units." The short cord refers to an 8 foot rick which is 4 feet high but cut to firewood length, generally 2 to 3 feet long. Likewise a long cord is a 4 x 8 foot rick of bolts in excess of 4 feet and up to 8 feet long. Lumbermen also refer to 500 board feet as the equivalent of a standard cord of wood.

Today, United States pulpwood is cut in lengths of 2, 4, 5, 5.25, and 8.33 feet. The southern states pulp mills predominantly used wood 5'3" in length. (The major exception being West Virginia pulp mill at Charleston which accepts tree-length.) While the United States has many lengths of pulpwood and many measures of it, Canada and Europe have almost totally adopted the cunit, C-unit, or cubic-unit. This refers to 100 cubic feet of solid wood, not stacked volume.

Solid wood is the preferred unit of measure from the pulp mills viewpoint. A major work on the measurement
of the solid volume of wood was published by Taras (55) in 1956 and today is referenced as the authority in the field of measuring solid content of southern tree species.

The following table gives approximations of wood volume in various sized cords of ricks; however, these estimates of rick volume are admitted to have great variation.

<table>
<thead>
<tr>
<th>Rick Size</th>
<th>Cu. Space</th>
<th>Cu. Volume (Wood &amp; Bark)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 x 8 x 4</td>
<td>128</td>
<td>90</td>
</tr>
<tr>
<td>4 x 8 x 5</td>
<td>160</td>
<td>113</td>
</tr>
<tr>
<td>4 x 8 x 5.25</td>
<td>168</td>
<td>119</td>
</tr>
<tr>
<td>4 x 8 x 6.</td>
<td>192</td>
<td>136</td>
</tr>
<tr>
<td>4 x 8 x 8.33</td>
<td>266.6</td>
<td>181</td>
</tr>
</tbody>
</table>

Variation in cubic volume is a function of the species, method of piling, diameter, stick length, straightness and freedom of knots. Values for variation due to these factors are given by Taras (55). Despite these variations there has never been a simpler or more convenient method found to measure wood. In the Lake states, a value of 79 cubic feet of solid wood is the estimate of a standard cord. The South produces only 72 cubic feet of wood per cord for pine and 79 cubic feet for hardwoods according to the U.S. Forest Service. Mills, however, have traditionally computed their own values of solid wood per cord and weight of wood per cord based on the size and quality of wood which they purchase.
An ideal measure of volume would be absolute, unambiguous, accurate, simple and cheap. The method closest approaching these criteria utilizes the Archimedes principle of water displacement. However, the xylometer is still in the experimental stage.

**Weight Measure**

Mine timber and pine stumps have been bought by weight for many years. Today we find there is a great increase in the appeal of buying by weight. This has been attributed to the change in the locale of the measurement and purchase of wood—from the forest to the mill or concentration yard (1). Since 1955, a large segment of the pulp industry has adopted weight scaling instead of volume estimation. This has grown in the same manner as volume measure, that is, each company has studied the wood it procures and obtained values which it alone uses. This is shown in the values used today for weight measure; prices are quoted on average weight per standard cord. Significantly not in use are the former measures of ton and hundred weight.

Factors contributing to variation of weight within a given species and area are wood volume, moisture content and density. Wood volume variations are discussed in wood volume measure. Moisture content varies for heartwood and sapwood. Density is affected by per cent of summer-wood, growth rate, and position in tree, i.e., density is lower
at the top of the stem than at the base. This variation in weight is illustrated by the following tables from Taras (55).

<table>
<thead>
<tr>
<th>Species</th>
<th>Specific Gravity</th>
<th>Moisture Content(%)</th>
<th>Density #/cu.ft.</th>
<th>Solid Vol/cord</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loblolly</td>
<td>0.46</td>
<td>110</td>
<td>60.3</td>
<td>72</td>
</tr>
<tr>
<td>Longleaf</td>
<td>0.53</td>
<td>105</td>
<td>67.8</td>
<td>72</td>
</tr>
<tr>
<td>Shortleaf</td>
<td>0.44</td>
<td>120</td>
<td>60.4</td>
<td>72</td>
</tr>
<tr>
<td>Slash</td>
<td>0.52</td>
<td>120</td>
<td>71.4</td>
<td>72</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Species</th>
<th>Weight of Solid Wood/cord (lb.)</th>
<th>Estimated Bark (lb.)</th>
<th>Total Weight (lb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loblolly</td>
<td>4,342</td>
<td>700</td>
<td>5042</td>
</tr>
<tr>
<td>Longleaf</td>
<td>4,882</td>
<td>650</td>
<td>5532</td>
</tr>
<tr>
<td>Shortleaf</td>
<td>4,349</td>
<td>500</td>
<td>4849</td>
</tr>
<tr>
<td>Slash</td>
<td>5,141</td>
<td>500</td>
<td>5641</td>
</tr>
</tbody>
</table>

While Taras has computed total weight very accurately, he has also shown the limitation which has yet to be overcome. "For each 0.02 change in specific gravity at 100% moisture, wood weight will change approximately 2.5 lb./cubic foot." Also, if moisture content varies five percent the weight change will be 1 to 2 lb./cubic foot. Therefore, if a 72 cubic foot cord changed 0.02 specific gravity and five percent in moisture the weight change could be as great as 280 lb.

Contrary to popular belief, it has not yet been proven that weight scaling is greatly superior to measuring stacked ricks from the standpoint of predicting actual amount of solid wood in a cord (1).
Reasons for Weight-Scaling Pulpwood

1. It encourages delivery of green wood to the mill. The mills prefer green wood as it will store longer and yields more usable fiber if pulped when green.

2. It is a fast method requiring no special handling, thereby saving time and money.

3. Weight scaling is more objective than cordwood scaling and positive records of all transactions are automatically provided by the weight tickets. Weight scaling eliminates human error or indifference in manual volume calculations.

4. Incentive is provided for better piling on trucks, thereby increasing volume handled.

5. Woodyard inventories are easier to maintain because of greater uniformity in record keeping. Thus it is a much more satisfactory way to do business with a bulk product.

Factors Favoring the Small Producer

There are several factors today which tend to sustain the existing pulpwood supply system. These factors are economic and environmental in nature.

Pulpwood harvesting in the South was originally a part-time job for the farmers after the crops had been planted and again after the harvest. It was ideally suited for the farmer as the forest was just too cold and wet in
the winter and too hot and humid in the summer. The small amount of capital needed to be a part-time producer allowed nearly everyone to do some pulpwood cutting. The price of a chain saw for felling and bucking efficiently, and the existence of an old truck for hauling the wood is all that is necessary to become a pulpwood producer even today.

The standard 5'3" bolt still needed by today's mill perpetuates the part-time producer. This situation stems directly from the original reason for shortwood—ease of manual handling. (The average pine bolt weighs approximately 65 lbs.)

Land ownership patterns of the South have reduced the size of privately owned timber tracts available for cutting. Thus, small tract size (less than 100 acres) (22) has favored the small, part-time producer. This absence of large blocks of available timber retards the trend toward mechanical harvesting of pulpwood. It is too expensive to be constantly moving heavy equipment to a new stand. A desired size stand for optimal harvesting is given to be approximately 650 acres (10).

Recent years have seen the emergence of the full-time producers. Their initial capital investment may not be much larger than that of a part-time producer (two saws and a two-ton truck, as opposed to a saw and any truck); however, in order to produce more than 30 cords per week, additional investment in machinery is needed. Some of the
independent producers that harvest 80 to 100 cords a week, have an investment of $40,000 and more in machines. Yet a paradox exists when the profit of the small manual producer and the profit of the mechanized producer are compared. Initial studies by Pietro Fenu and Walt Cosby of the S.E.A. Pulpwood Research Program at Georgia Institute of Technology, indicate that profits taken from the balance sheet of the producer, will be virtually independent of the scale of investment. This is startling! In other words, the risk taken by investing in machinery produces a larger cash flow but does not increase profit significantly; however, this area of study is still being pursued.

Another factor which has played a part in limiting the size of an independent producer is his ability to supervise and obtain steady employment for more than a single harvesting crew. Those men which have the ability are often lost to the factories where the work is steady, indoors and much less demanding physically and mentally (11, 30). However, there does exist a certain amount of prestige associated with owning and operating a pulpwood harvesting business. This prestige and independence of the operator are perhaps the biggest factors which have kept the supply of pulpwood equal to the demand. Money from pulpwood harvesting has yet to make anyone a millionaire.

These factors (small tracts, low capital needed to enter the business, independence, prestige, and cost of
mill and producer conversion to other harvesting methods) are still valid reasons for continuing with the existing system. However, in order to maintain the present price paid for pulpwood and insure that supply will not fall below demand, the system must change. An example of such a system change can be seen in American farming. Farming has been changed during the past 50 years by the economics of scale, into highly specialized production of a crop by each farmer. Pulpwood producers can look toward similar high-volume specialization if the fight against pulpwood cost increases is to be waged successfully by the mills.

Further, it must be recognized that pulpwood harvesting is physically demanding. Coupled with the uncertainties of woods work (weather, demand, and available forest), pulpwood production is not as attractive as many other jobs.

Rural out-migration can be seen clearly from the following statistics of the U.S. Census Bureau. The 12 Southeastern states had 3.24 million farm workers and 1.87 million farms in 1950. By 1959 these figures had decreased to 2.22 million workers on 1.15 million farms. Between 1959 and 1964 the number of farms across the entire South declined 16 per cent. This resulted in a loss of only slightly more than 11,000 acres as the size of the average farm climbed from 217 acres to 252 acres. The population shift in the South is also revealed in the 1950 and 1960 census figures. These figures show that the South had a loss of
2.5 per cent in rural population and a 42 per cent increase in urban population for a net increase of nearly 17 per cent. Thus, while Southern rural emigration and job-creating industrialization have not lead to pulpwood shortages so far, this possibility exists in the future (20). This, again, points toward mechanization and specialization in order for pulpwood harvestings to remain economical and yet an attractive means of livelihood.
CHAPTER IV

PROCEDURE

Introduction

The procedure used in this investigation was subdivided into two separate areas. The first was the area of systems analysis and concerns the extraction of the real world system from the environment and preparation of the models. The second area was the use of the models for the development of the simulation programs.

System Analysis

Approach

In selecting an approach for modeling the system, the original choice was to try and describe each basic component by a mathematical equation and solve the system of equations by LaPlace Transformations and Matrix Theory. As system research progressed and knowledge of the system variables increased there were obvious indications that a pure formal, rigorous mathematical approach would not necessarily yield a solution. Further research into methods of solution of complex system models indicated that simulation using Monte Carlo methods could be of use in this case.

Once simulation was selected, two problems arose:

1. Since simulation requires an enormous number of
arithmetical calculations, a computer is necessary.

2. General purpose language programming for simulation of this type is most tedious, time-consuming, and not necessarily the most efficient method.

Solution to these problems arrived in the Fall of 1967 with the arrival of a UNIVAC 1108, a high speed digital computer, equipped to handle the "General Purpose System Simulator II (GPSS-II)" language.

With the decision to use GPSS-II simulation language on the U-1108 computer, the method of approach can be broken into eight phases. These phases are as follows: (1) system limit definition, (2) reticulation, (3) abstraction, (4) measurement, (5) identification, (6) solution, (7) optimization, (8) validation.

System Definition

The first step toward an analysis of a system through modeling is to define the system and its environment. The real world system under consideration in this thesis are those functions which are performed by the pulpwood producer. This means the system will start with a stand of trees ready to be harvested and will terminate when the 5'3" pulpwood bolts have been brought to the concentration yard for rail shipment to the mill. The environment consists of all other factors which provide information for the input channels which the harvester uses to decide when and where to cut and how much to cut. These information
Figure 1. Environmental Factors In Pulpwood Harvesting
Figure 2. Interchangeable Blocks for Three Common Shortwood Harvesting Systems
inputs from the environment would correspond to the woodlot owner, the pulp mill procurement manager, the concentration yard operator, and the forestry agent of state or federal government.

In this harvesting model we summarize all environmental inputs when we say we have a stand of trees awaiting harvesting. It is also assumed we have a market which will accept the pulpwood. Our system and its environment are now defined with these two simplifying assumptions.

**Reticulation and Abstraction**

Three common harvesting methods were reviewed. The three systems were then reticulated into basic operations through product flow charting techniques. The sequence of operations of these systems is shown in Figure 2. The systems contain a total of 12 different operations.

Since each operation is assumed to be independent, there are many possible combinations of the 12 basic operations into workable systems. In order to establish all the combinations which were reasonably realistic, the technique used in the Critical Path Method of project management was utilized since the possible precedence/relationships of each operation were known. Portrayed on Figure 3 are the 28 possible, realistic combinations of the basic harvesting system components.

**Identification**

This phase of the analysis has resulted in a listing
A Flow Diagram of Basic 5'3" Pulpwood Harvesting Operations
<table>
<thead>
<tr>
<th>Sys. No.</th>
<th>Harvesting Operation Number Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>20 31 32 51 52 62 70</td>
</tr>
<tr>
<td>2.</td>
<td>20 40 31 32 51 52 62 70</td>
</tr>
<tr>
<td>3.</td>
<td>20 31 40 32 51 52 62 70</td>
</tr>
<tr>
<td>4.</td>
<td>20 30 51 52 62 70</td>
</tr>
<tr>
<td>5.</td>
<td>20 40 30 51 52 62 70</td>
</tr>
<tr>
<td>6.</td>
<td>20 31 32 51 62 70</td>
</tr>
<tr>
<td>7.</td>
<td>20 40 31 32 51 62 70</td>
</tr>
<tr>
<td>8.</td>
<td>20 31 40 32 51 62 70</td>
</tr>
<tr>
<td>9.</td>
<td>20 30 51 62 70</td>
</tr>
<tr>
<td>10.</td>
<td>20 40 30 51 62 70</td>
</tr>
<tr>
<td>11.</td>
<td>20 31 32 61 70</td>
</tr>
<tr>
<td>12.</td>
<td>20 40 31 32 61 70</td>
</tr>
<tr>
<td>13.</td>
<td>20 31 40 32 61 70</td>
</tr>
<tr>
<td>14.</td>
<td>20 30 50 61 70</td>
</tr>
<tr>
<td>15.</td>
<td>20 40 30 50 61 70</td>
</tr>
<tr>
<td>16.</td>
<td>20 31 32 50 61 70</td>
</tr>
<tr>
<td>17.</td>
<td>20 40 31 32 50 61 70</td>
</tr>
<tr>
<td>18.</td>
<td>20 31 40 32 50 61 70</td>
</tr>
<tr>
<td>19.</td>
<td>20 31 32 60 70</td>
</tr>
<tr>
<td>20.</td>
<td>20 40 31 32 60 70</td>
</tr>
<tr>
<td>21.</td>
<td>20 31 40 32 60 70</td>
</tr>
<tr>
<td>22.</td>
<td>20 30 60 70</td>
</tr>
<tr>
<td>23.</td>
<td>20 40 30 60 70</td>
</tr>
<tr>
<td>24.</td>
<td>20 30 50 60 70</td>
</tr>
<tr>
<td>25.</td>
<td>20 40 30 50 60 70</td>
</tr>
<tr>
<td>26.</td>
<td>20 31 32 50 60 70</td>
</tr>
<tr>
<td>27.</td>
<td>20 40 31 32 50 60 70</td>
</tr>
<tr>
<td>28.</td>
<td>20 31 40 32 50 60 70</td>
</tr>
</tbody>
</table>

*Figure 4. Possible Combinations Of Harvesting Operations*
of those factors effecting each operations productivity. The operations are listed as follows, with factor explanations given as required:

(1) Planning, Moving and Felling of Tree (Block 20)

(a) Type of harvesting operation

1. Seed Tree
2. Select Cut
3. Clear Cut
4. Multi-product Harvesting

(b) Terrain

1. Slope
2. Soil moisture
3. Obstacles
   a. Rivers and creeks
   b. Rock and crops
   c. Windfalls
4. Underbrush

(c) Stand Characteristics

1. Spatial Distribution
2. Diameter Distribution
3. Individual tree characteristics

(d) Species

1. Softwoods
2. Hardwoods

(e) Extra Work Required (Swamping, pre-measuring, etc.)

(f) Crew Organization (generally one man working alone is 2/3 as effective as two men) (14).

(g) Method of Cut

1. Chain Saw
2. Hydraulic Shear
3. Handcut

(2) Bucking, Limbing and Topping (Block 30)

(a) Log Size
1. Diameter
2. Length

(b) Species
1. Softwood
2. Hardwood
3. Limbiness

(c) Felling Pattern
1. "Hang-ups"
2. "Cross-overs"
3. Obstacles

(d) Slash Disposal

(e) Measuring Method

(f) Method
1. Multi-function machine
2. Chain saw
3. Hand saw

(3) Skidding or Pre-haul (Blocks 40 and 52)

(a) Weight Considerations
1. Sufficient logs for optimum load
2. Sufficient chokers available

(b) Terrain
1. Slope
2. Soil and soil moisture content
3. Obstacles
4. Brush

(c) Distance Per Turn

(d) Non-effective Time
1. Choking of logs (grapple or cable)
2. Awaiting a load
3. Unloading
4. Trail/road repairs
5. Machine repairs

(4) Stack or Load Pallet (Blocks 50 or 51)

(a) Weight
(b) Height
(c) Distance (major factor)
(d) Number of Pieces per Stack (the larger the required size stack, the longer the distance necessary to get the wood).

(5) **Loading or Transfer** (Blocks 60, 62 and 63)

(a) Manual—same factors as "Stack" except that height is now the major factor and distance a minor factor.

(b) Mechanical

1. Number of pieces loaded per cycle
2. Effective crew loading time
   a. Available wood
   b. Available truck

(6) **Transport** (Block 70)

(a) Size of Load

1. Truck limits
2. Legal road limits

(b) Length of Haul

(c) Speed Limits

1. Load Size
2. Road Quality

(d) Effective Hauling Time

1. Load and unload time
2. Delays in loading and unloading
3. Mechanical failures

(7) **Buck** (Block 32)

(a) Log Size

1. Diameter
2. Length
3. Hardwood or Softwood

(b) Site and Arrangement of Logs

1. In the woods
2. On a landing

(c) Measuring

(d) Method

1. Chain saw
2. Slasher
3. Handsaw

(8) Limb and Top (Block 31)

(a) Log Length

(b) Species

1. Softwood
2. Hardwood
3. Limbiness

(c) Site Obstacles

(d) Slash Disposal

(e) Method

1. Manual
2. Mechanical

**Measurement**

Measurement of the factors identified in each operation proved to be the hardest part of the work. Many factors are presently being researched by various institutions and published data is often non-existent. A list of all variables and parameters considered in the simulation program is given in the following section discussing the simulation program.

**Solution**

The solution phase of the analysis resulted in the generalized harvesting operation computer program built for simulation purposes. This type simulation program was
designed to enable researchers to make (1) comparisons of alternatives, and (2) studies of system response to random variations in parameter values. This experimental work is left for those who follow on with this work.

**Optimization**

While normally a part of systems analysis such as this, optimization of the system models was not attempted. It was not a thesis objective. Basically, the models are for determining system effects due to random changes in system values. Those persons interested in a specific system may utilize these models and the simulation program for optimization studies however.

**Validation**

The problem of validation is most critical for macroscopic models with relatively few variables. For microscopic models, such as are employed in this research, the problem is minimized through the use of detailed model structure corresponding to the real world system. Validation of the pulpwood harvesting models has been achieved through the isolation, identification, and representation of system component relationships and the correlation of the results with the real world system. The model should accurately portray the real world if it is to serve as a realistic point of departure for conceptual innovations.

**The Computer Programming Procedure**

The translation of the systems described previously
in this chapter, and depicted in Figure 2, into a general purpose computer model employing GPSS-II is a straightforward procedure. Since each system component shown in Figure 2 was assumed independent except for the relationships shown in that figure, the programming consisted of creating 12 semi-independent programs with a common origin and end. The programming of each component is discussed by following through the basic stump-to-stump system, then systematically considering the remaining operations present in the other basic systems.

The details for compilation of the computer program will not be discussed here. The procedure is similar to that of other languages and is covered thoroughly in (57). Appendix III contains a print out of the completed program. The control cards required at the beginning and end of the program are also given in Appendix III.

The Forest Generator (Simulation Program Origin)

The Forest Generator is the common origin for all system models or variations. It consists of a GENERATE block, a COMPARE block, a series of ASSIGN blocks, and a QUEUE block. The GENERATE block initiates a continuous flow of transactions to be processed through the system. Each transaction is analogous to a tree in the forest and therefore is a discrete entity. Values of variables needed to uniquely define the "tree" are assigned to the transaction as it passes through the series of ASSIGN blocks.
Values used to describe each tree are randomly chosen from a distribution of values approximating the probability of occurrence in the real world. Specifically, the values assigned describe: (1) the distance from the last tree harvested, (2) the diameter of the stem at breast height (D.B.H.), (3) the length of useable stem (as a function of D.B.H.), and (4) underbrush. These values are permanently assigned as they are used more than once in the program.

Distributions describing the range of values for these variables are found in program functions 16, 13, 11 and 17 (FN 16, FN13, FN11 and FN17) respectively. (These functions and all other data distributions described in program functions are shown graphically in Appendix V.) Variables used in only one operation have their values generated and assigned as required. The transactions are now placed in a queue, described by a QUEUE block, to await processing through the system. The COMPARE block serves to regulate the flow of transaction into the system so there will always be trees available to harvest, but not so many as to overflow the computer capacity for this section of the program.

Plan, Move and Fell (Block 20)

The felling operation consists of three major elements—moving to the tree, planning the fall of the tree, and actually severing the stem from the stump. The first and last elements are essentially the same in all harvesting operations. The planning of the fall is dependent upon
several exogeneous variables: the microtopography, wind direction and velocity, tree growth irregularities (i.e., lean or uneven branch distribution), and the silviculture/management practice for the stand. Stand management may dictate (1) a clear-cut harvesting operation, or (2) harvesting of selected trees from storm damaged stands or plantation thinnings, or (3) harvesting of all but selected trees (to allow for natural stand regeneration). These are the major factors considered in some degree by the feller before the severing of the tree actually takes place.

Since clear-cut harvesting is common and can be reasonably assumed to minimize the moving, planning, and felling time, a constant factor of unity has been used to signify clear-cut harvesting in the simulation program. Should research be able to quantify the effect of type of harvesting on the felling operation, an appropriate value may be inserted in place of unity, i.e., place a value of 2 in program parameter simulating the type of harvesting operation if cutting all but selected trees takes the felling operation twice as long as in clear-cutting.

The total time allowed for the felling operation is given by Variable Statement No. 1 (V1) and is computed as follows:

\[
V1 = \left( \frac{\text{Distance to Tree}}{5} + \frac{\text{Brush Factor}}{2} \right) \times \text{Type Harvesting Operation} + \text{Time to Sever Stem}
\]
Distance to Tree values are randomly selected from a distribution described in program function 16. Underbrush Factor values are randomly selected from a distribution described in program function 17. As data for the Underbrush Factor originally came from a skidding operation study, a constant of two was assigned to modify the data to allow for its use in this section. Type Harvesting Operation is signified by the constant one in this thesis (see previous paragraph). Time to Sever Stem is dependent on tree diameter. The distribution is described in program function 10.

The constant five, used as a divisor of Distance to Tree, is an arbitrary conversion factor to convert distance into time. This is required because the basic unit of time in the program is the 10-second interval. The value of five was chosen as the pace of the average feller moving his equipment tree to tree as it allows some consideration for the variation in terrain, i.e., a feller moves five feet per 10 seconds.

The specific variables considered are:

(1) Tree spacing
(2) Stem diameter, breast high
(3) Rate and method of cut
(4) Underbrush
(5) Terrain variables are indirectly accounted for in the factor converting tree spacing into time to move
between trees.

Assumptions for this operation are:

(1) Cut is made with portable chain saw
(2) Felling crew is a single man
(3) Clear cut harvesting operation

Assumptions (1) and (2) can be changed to allow for consideration of other methods of felling (i.e., mechanical or hydraulic shear, hand saw, etc.). This would be accomplished by specifying the desired distribution of rates of cut in FN10 and changing the parameter constant (presently equal to five) to reflect the average rate of movement over the terrain between trees. A short discussion concerning assumption (3) is found in the second paragraph under Plan, Move and Fell.

The entire operation is simulated by a single program block named HOLD. The operation of the block allows for the consideration of one transaction at a time. The transactions are held in the block for the time specified by V1, then released to the system.

Buck, Limb and Top (Block 30)

This operation has three major elements, namely, bucking, limbing and topping. The purpose of the operation is to divide the merchantable part of the tree into the desired product—a pulpwood bolt of 5'3". Since in many systems the bucking operation does not take place concurrent with limbing and topping, the time allowed for this con-
current operation is assumed to be equal to the sum of the parts. The total operation time is given in Variable Statement No. 2 (V2):

\[ V2 = V3 + V4 \]

where \( V3 \) is the variable statement used to compute the time for the limbing and topping operation, and \( V4 \) is the variable statement used to compute the bucking operation time.

The equation for computing Limbing and Topping time is given in Variable Statement No. 3 (V3):

\[ V3 = \text{Limb-Top Time} \times \text{Limb Factor} \]

Limb Factor values are randomly generated from a distribution described by function seven (FN7). Limb-Top Times are randomly generated from a distribution described by function 8 (FN8).

The equation for computing the Bucking operation time is given in Variable Statement No. 4 (V4):

\[ V4 = \text{Time to Sever a Bolt} \times \text{Number of Bolts} \]

Time to Sever a Bolt is dependent on stem diameter. Values are generated from a distribution described in function 27 (FN27).

The Number of Bolts is obtained from Variable Statement No. 7 (V7) which divides the merchantable stem length (previously determined) into five foot units, discarding
the remainder. (Note: The figure of five feet is used in place of 5'3" \(5.25\) due to program restrictions.)

The assumptions made with respect to this operation are:

1. There is no time chargeable to slash disposal
2. The method of operation is one man with a chainsaw.
3. Time used in measuring bolt length and moving to next bucking point is covered in the time allowed for the operation.

Assumption (1) is realistic as slash is left where it falls in most pulpwood harvesting operations. The second assumption can be changed to consider mechanization of limbing, topping, and bucking provided the bucking time can be differentiated from limbing and topping, by re-defining FN27 and FN8. To allow for a separate consideration of a variable for measuring would require some reprogramming and some field work to gather necessary data.

The operation of bucking, limbing, and topping is simulated by a single program block named HOLD in the same manner as the previous operation of moving, planning, and felling.

Stack (Block 50)

The Stack may be either of two types—a rough and tumble pile or a neat rick. Neat piles are built when the bolts are to be loaded or forwarded mechanically. Rough
stacks are generally made to facilitate manual loading at the stump.

The time required to rough stack the bolts of one tree increases directly with increasing number of bolts per stem due to increasing distance to the last bolts. This relationship of distance, time and number of bolts is formulated in FN12 so that given the number of bolts per tree, the time to rough pile "n" bolts is found directly.

The time necessary to build a neat, raised stack, backed up against a tree was observed and measured for a fork lift forwarder operation. Building this type stack was found to take nearly three times as long as making a rough pile of the same size. Much of this increased time was attributed to the specific working conditions under which the data was collected. It is hypothesized that for simulation purposes, if the time to form a rough and tumble pile is given in FN12, then the time to form a neat stack of parallel bolts could be simulated by using a mean of two in the simulation program, thereby simply doubling the time required for the stacking operation.

The major limitation of this system component is its lack of ability to specify a minimum or maximum size for a stack. The specific assumption was made that the man performing the bucking, limbing and topping operation would also perform this operation. This assumption can be relaxed by changing the program facility number of this block to
allow for simulation of the stacking operation by someone other than the bucker.

Load Manual (Block 60)

The transactions arriving at the loading operation may represent a single tree, as in the stump-to-stump system, or several trees, as in a skidder system where several trees are grouped together for skidding and successive operations. The total time for the actual loading of the bolts is given by Variable Statement No. 5 (V5) as follows:

\[
V5 = \text{Time to Load Bolts} + \text{Time to Move Truck}
\]

Time to Load Bolts is dependent on the number of bolts which the transaction simulates. This value is taken from the distribution found in program function 19 (FN19) which is based on time for loading by two men. Time to Move Truck to the pulpwood bolts considers the probability of having to move and the distance to move. The time value assigned is randomly selected from the distribution described in program function 9 (FN9).

The actual loading is simulated by the HOLD block previously described and each transaction is held in the block for the time specified by V5. The transaction now enters a storage, denoted by an ENTER block. This simulates the storage of the bolts on the truck while the load is being built. The storage computes the volume of the tree (or trees) described by the entering transaction and uses
the volume of the tree to compute the load now on the truck. The present capacity is compared (by use of a COMPARE block) with a value of 220 to see if the truck has been loaded. The value 220 approximates three cords of pulpwood (73 cubic feet per cord) and is used as the load capacity of the transport vehicle. When 220 cubic feet or more of wood has entered the storage, the transaction (now simulating a truck load) is released by use of a LEAVE block. The LEAVE block shows that 220 cubic feet of wood have been removed from the storage.

An assumption is made that the truck will be moved occasionally to minimize handling; however, other conditions, such as manual loading at the brow, can be simulated by altering FN9 to reflect the new condition.

**Transport** (Block 70)

The transportation of the pulpwood from wood to mill or concentration yard is simulated by an INTERRUPT block. With the assumption of only one truck for pulpwood hauling, truck loading and pulpwood hauling can not take place simultaneously. The INTERRUPT block provides the means of stopping the loading operation (or transfer operation of Block 63) while the hauling of the pulpwood is in progress. A general reprogramming of this operation would be necessary to allow for more than one truck.

The variables considered are woods-road and highway distance travelled. Values for each distance are randomly
selected from distributions found in program functions 15 and 14 (FN15 and FN14) respectively. An average speed of 3 m.p.h. has been assumed for woods-road travel and 30 m.p.h. for paved road travel. The time for one way hauling is given in Variable Statement No. 6 (V6) as follows:

\[
V6 = \text{Woods Road Distance} \times 120 + \text{Paved Road Distance} \times 12 + \text{Unloading Time}
\]

The constant values of 120 and 12 are conversion factors for changing the distance travelled over each type road into time spent in travel assuming 3 m.p.h. and 30 m.p.h. average speeds for the respective road types. Unloading Time at the woodyard is randomly selected from a distribution described in program function 28 (FN28). The values of FN28 are one-half the actual values in order that the round-trip may be computed by multiplying V6 by two. The value two is specified as the operation mean.

**Program Termination**

All transactions released from block 70, transport to woodyard, are sent to the TERMINATION block which counts the number of transactions arriving. The program is terminated by either placing a limit on the number of terminations or by the relative time simulated in the program. The program is designed to stop after 2880 time units have elapsed. With each time unit equal to ten seconds, an eight hour day will be simulated. Following the print out
of a day's operation, the program will run for 14,400 time units simulating a five day work-week and print statistics covering this period of time. The program is ended at this point.

Since sizeable wood inventories of felled or bucked trees are not common, the simulation model is not allowed a "warm-up" time to remove initial transients. This is in keeping with observed operations in the real world systems.

One path has now been traced across the pulpwood harvesting system shown in Figure 2. The remaining blocks are now covered in two sequences. The first series of blocks are contained in the Basic Mechanized Harvesting System (Blocks 31, 40, 32, 61). The second series of blocks are unique to the Palletized Harvesting System (Blocks 51, 52, 62).

Limb and Top (Block 31)

The limbing and topping operation has been described as the product of two factors for the simulation program. These factors have been designated Limb and Top Time and Limb Factor. A distribution of values for these factors are found in program functions 8 and 7 (FN8 and FN7) respectively. The Limb Factor accounts for the large variation in the number of limbs found on typical pulpwood species. Loblolly pine is an example of a typical pulpwood specie which requires a minimum amount of limbing. The other extreme is represented by Virginia Pine. No attempt was made to relate
tree height to number of limbs or time to limb and top. Limb and Top Time is used to describe the actual length of time taken for the operation. Selection of values for each factor is randomly made from the appropriate program function.

See Limb, Buck and Top (Block 30) for a discussion of assumptions and method of simulation in the program.

**Skid (Block 40)**

The skidding operation is similar to the loading operation with respect to the programming in that a single tree is not the basic unit considered. The skidding operation considers a load of logs. In order to insure a consistent load for each trip, the model groups the transactions such that each group will contain a minimum of 50 cubic feet (0.68 cords) of solid wood, with a maximum permissible load equivalent to 65 cubic feet (0.89 cords). These load values were selected to simulate the productive capacity of the smallest commercial skidders.

As the transactions are made available to the skidding operation in the program, the volume of each tree is computed by Variable Statement No. 9. The formula for the volume of a cylinder is used with D.B.H. and top diameter of five inches (over bark) being averaged and converted to feet to obtain the diameter used in the formula. The transaction enters a storage which is the grouping function, by using an ENTER block. The storage capacity is defined as
the skidder maximum load of 65 cubic feet. Units of capacity are consumed according to the value of the tree Volume. Should the program value of 65 be exceeded, due to the value of the accumulated load approaching the minimum load point, the transaction will be held for the next turn. From the available transactions awaiting skidding a tree of appropriate size will be selected to fill out the present turn.

The volume of the load, the number of bolts in the load, and the number of logs composing the load are computed and placed in SA/EX cells. Cell contents are printed for each skid load. The time and distance of the skid are computed in several steps. First, skid distance, in feet, is randomly chosen from a distribution contained in program function 22 (FN22). This value is used as the argument of program function 21 (FN21) which results in a productive time per turn proportional to distance. Added to productive time is an Underbrush Factor. The value of the underbrush factor is randomly chosen from the distribution contained in FN17. A constant figure of 30 per cent is used as the average value of skidder non-productive time. (Non-productive time is any time the skidder is utilized for work other than that involved in choking, skidding, unloading and return empty.) Variable Statement No. 12 (V12) is now used to compute the total time of the turn.

\[
V12 = (1 + .30) \times (\text{Skidder Productive Time} + \text{Underbrush Factor})
\]
The simulation of the skidder operation considers only a single skidder. This is justified with respect to the objective of this study—to simulate the common, short-wood systems of pulpwood harvesting.

The skidder simulation considers the following variables:

1. Distance,
2. Productive and non-productive time,
3. Loading, and
4. Soil condition.

Soil condition is considered by inclusion of one of two distributions available for FN21 to reflect dry soil or wet soil; the decision of which function will be used must be made during the assembly of the program. "Dry" soil is defined to exist when a loader skidder looses traction less than 25 per cent of the skid distance. Definition of "wet" soil is thus implied as a loss of traction by the skidder over a distance in excess of 25 per cent of the skid distance.

Buck (Block 32)

The bucking operation, and procedure used to simulate the operation by the program, have been discussed previously in the Limb, Buck and Top operation (Block 30). The transactions which enter Block 30 represent discrete trees; however, transactions could enter the bucking operation of this block representing a skid-load of stems. A
transaction representing several stems will have been modified by the Skid operation to reflect the change in the number of bolts to be bucked.

A discussion of the assumptions made in the program with respect to bucking have been discussed in Block 30, Limb, Top and Buck.

The bucking operation is simulated by a HOLD block.  

**Mechanical Load (Block 61)**

The transactions arriving at the loading operation may represent single trees or groups of trees depending upon the preceding system operations. The total time for the actual loading of the bolt is given by Variable Statement No. 14 (V14) as follows:

\[ V14 = \frac{\text{Number of Bolts}}{\text{Bolts per Load Cycle}} \times \text{Loader Machine Cycle Time} \]

The Number of Bolts represented by the transaction has already been determined in previous operations. The Number of Bolts per Loader Cycle could have been obtained randomly; however, a constant of six has been used to indicate that an average of six bolts are loaded onto the truck in every load cycle. Variation in operation time has been introduced by the random choice of a cycle time from the distribution of values located in program function 24 (FN 24).

The loading is simulated by the use of a HOLD block which allows each transaction in turn to be held for the
time specified by V14. The transactions then enter a storage simulating the wood laying on the truck and the amount of occupied space is computed. A COMPARE block checks to see if the truck has reached its capacity. When this occurs, the storage is decreased by the size of the truck load and the transaction proceeds to Block 70, Transport. The loading and transportation operations are mutually exclusive.

Truck capacity is defined in the same manner as was discussed in Manual Load (Block 60).

Load Pallet (Block 51)

The pallet loading operation may take place either at the stump or at the brow. Each pallet, simulated in the program by STORAGE block No. 3, has a capacity of 1.5 cords expressed as 109 cubic feet of solid wood. Loading a pallet is similar to manually loading a truck. The major advantage to pallet loading is the decrease in the height each bolt is lifted before being placed in the load. This is reflected in the loading time when compared to manual truck loading. The pallet is also capable of being positioned in areas which would be inaccessible to a truck, thereby decreasing the distance the average bolt is carried; however, decreased loading distance leads to increases in the distance of the pre-haul.

The time value used to simulate loading time is an average time per bolt randomly chosen from function 18 (FN 18). This value is then multiplied by the number of bolts
represented by the transaction. This value is computed by Variable Statement No. 15 (V15) as follows:

\[ V15 = \text{Load Time per Bolt} \times \text{Number of Bolts} \]

In specifying the data distribution of FN18, the range of distances a bolt is carried and the probability of any given distance is considered. The major assumptions of this operation are that there will always be a pallet available for loading and pallets are positioned only once.

**Pre-Haul (Block 52)**

Each time a pallet is loaded, it is removed to the landing provided the pre-haul vehicle is available. The time for the operation has been based upon pre-haul distance with an average speed of 150 feet per minute. Allowance for hook-up and unhook times is not made because of their small time in comparison to haul time. Variable Statement No. 16 (V16) is used to compute the one-way pre-haul time as follows:

\[ V16 = \frac{\text{Pre-haul Distance}}{150} \times 6 \]

The constant 150 is the average speed in feet per minute which results in the pre-haul distance expressed in units of minutes. The constant six converts minutes into the program time units of ten seconds. Pre-haul Distance is randomly selected from function 26 (FN26). A mean of two is used to simulate the round-trip.
Transfer (Block 63)

The transfer operation consists of winching five pallets onto a flatbed trailer. After the trailer is positioned for loading, the pallets are winched on one at a time and chained down. The time for this operation is randomly selected from an equi-probably spread of times which have a mean of 30 minutes and range from 20 to 40 minutes.

The operation is simulated with a HOLD, an ENTER, and LEAVE blocks. Pallets arrive singly but leave five-at-a-time as they would on a truck. The program operates in essentially the same manner as the mechanical or manual load operations. With respect to the transport operation, an assumption is made that the transport of palletized pulpwood also involves both dirt and paved roads.

This completes the programming of the simulation model and the alternative operations. At this point, certain assumptions must be made about the models relation with the real world system. That is, the distributions for the values of variables which have been selected to adequately represent the action of the environment on the system and the subsequent reaction of the system must be determined. In this thesis, particular distributions used to generate the values of variables were derived from available data sources and are assumed to approximate the real world values. This assumption is justifiable only because of the impending
release of a major, detailed study of Southern pulpwood producers by the American Pulpwood Association and the limited time available to the research team at Georgia Institute of Technology for data collection. A continuation of this research is planned by the S.E.A. Pulpwood Research Program team when the data collected in the A.P.A. Producer Survey is released. Since consistent, comprehensive, and recent data is expected, research time was not devoted to an analysis of possible data variations due to source or methodology of collection.
CHAPTER V

RESULTS AND CONCLUSIONS

Discussion of Results

This research has resulted in the programming of a basic pulpwood harvesting model which allows 28 possible systems to be simulated. A total of 19 variables and 15 parameters are considered in the model. Due to computer software problems, only partial results are available from a simulation of the stump-to-stump harvesting system. Further research utilizing the harvesting simulation program is planned.

A sample program is given in Appendix IV along with its print out. The sample program simulated a four-man crew using the stump-to-stump harvesting system. The simulation results are identical with the real world system in respect to the day's production. The model shows that a second, three-cord load of pulpwood was in transit to the concentration yard at the end of the eight-hour day. Further, the limiting operations of the system are readily identifiable. In the sample program, the loading and transporting of the pulpwood (simulated by facility four) was found to be the limiting operation with the magnitude of the system restriction indicated by the 45 trees awaiting loading (the
length of queue four). It is expected that the length of this queue will decrease significantly with the inclusion of the delay function in the full model. The delay function will simulate the rest periods and machine maintenance times which are necessary and frequent with the heavy, manual work of pulpwood harvesting. The full model will also allow for a differentiation in the loading and transporting operations.

An indirect result is the formulation of the equations to yield time values for the system operations. The equations are empirical. They show that elemental operations and environmental factors can be quantified to yield realistic values.

The use of distributions to describe initial system conditions provides the model with a major advantage when compared to more conventional simulation models which use specific sets of initial conditions for each simulation. The distributions may be readily altered or re-designed by the user to allow for positive control of simulation experiments. Specific values for parameters are also used in the model initial conditions. Thus, the program responds to both constant and variable initial conditions during each run. The Monte Carlo technique of allowing random numbers to select values of variables from the variable cumulative probability distribution was used to minimize unintentional bias in value selection.
The results of the considerations of general system constraints are that the forces of price and volume required by the pulp mills will tend to accelerate the trend toward mechanization and specialization of the harvesting operations. Resisting this force are the factors of the present small size of the private wood lots available for cutting, the lack of large amounts of producer capital available for investment, and the social structure of the labor pool now engaged in pulpwood harvesting.

The investigation into methods of pulpwood measurement showed that neither weight measure nor volume measure are demonstrably superior to the other with respect to the amount of solid wood measured. Weight measure does have the five advantages as given in Chapter III.

Conclusions

Two conclusions can be directly drawn from the sample program. First, the model does represent the system, and second, quantitative insight into the real world system can be obtained from the model with respect to system limiting operations.

At this point, statistically designed experiments should be carried out to study the effects of combinations of parameters and variables of harvesting operations. Newnham reported that the cybernetic solutions of problems tested with his harvesting simulation program differed by 40 per
cent from calculated solutions suggested by others. However, a preliminary test simulating another type machine yielded "remarkably accurate estimates." This is expected to be the case with this model due to its scope.

It is anticipated that the main use of this model will be to allow for comparisons between harvesting systems. With the A.P.A. Producer Survey data, greater accuracy should be possible in system comparisons. System balancing and optimizing studies can also be aided with this model.

**Recommendations**

This thesis cannot be considered a completed research study. It is, however, a basis for further specific studies. Statistical experimentation with the model is definitely needed: first, to obtain comparative data between systems, and second, to obtain data on the differences in system output from actual and hypothesized data. Systems tested with actual and hypothesized data could represent comparing present and future systems.

A second study would be to enlarge the computer program to allow for the paralleling of equivalent operations and the splitting of a system into two or more systems. Technically, this would not be difficult. Related to this would be the harvesting model enlargement by the programming of a mobile, in-the-woods, chipper operation.

Finally, it is recommended that basic studies be
made at an elemental level on harvesting operations. There are many studies made on productivity rates and costs for each piece of woods machinery. However, a man that costs 15 to 40 thousand dollars in five years time has only an assumed capability. The laborer, his employer, and also science would benefit from the application of standard industrial engineering methods to this area.
APPENDIX I

THE NATURE OF THE
PULPWOOD HARVESTING RESEARCH PROGRAM AT
GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF INDUSTRIAL ENGINEERING
Nature of the Research Program*

Objectives

The objective of the Research shall be the structuring of a systems model or models sufficient to validly represent the endeavors involved in the "Harvesting and Transportation of Pulpwood." Such model or models shall portray the significant characteristics and constraints on such systems as they now exist, and as they are likely to exist prior to the year 2000. Such model or models shall portray the compatibility or incompatibility of the various existing resource ownership patterns, labor patterns, techniques of harvesting, and techniques of transportation; and such pattern and techniques anticipated prior to the year 2000. The resultant model or models shall have the ability of quantifying the productivity of the major resources utilized in the system and its relationship to economic investment and resource pricing.

Scope

The Research shall be limited to the "Southern Pines Producing" geographical region and shall consider the resource material for paper manufactured from the time of the

*Quoted from the Research Proposal to the Southern Executives Association.
planting of the seed to the time of chemical treatment of the fiber in the paper-making process. The Research shall consider transportation of the resource material on any fiber form from stump to paper-making facility. For purposes of model construction, one paper-making facility and its resource area shall be the endeavor unit to be measured, providing its interfaces with other adjacent facilities and resource areas are firmly delineated. A typical facilities or resource areas shall be given due consideration. Provision in the model or models shall be made to quantify the social and political interrelationships between the paper-making facility and its resource owners and processors equate them to the economic quantification of the model or models. Management techniques and business skills of the resource harvesters shall be given consideration in the model building processes.

Method of Approach

After an introductory and familiarization period necessary for the Research Group to become acquainted with the current state of the art, present characteristics and constraints on the system shall be defined and quantified using the systems approach for analytical purpose. Inputs, outputs, and levels will be explored for model compatability and typing and to define problem areas within the models. Various models of the present systems will then be designed for testing the present system, possibly using simulation
techniques apparently applicable. After problem areas have been minimized, then the most optimum model or combination of models will be selected for testing the parameters for sensitivity. Further testing shall be made to insure the model or combination of models is responsive to the Objectives of the Research Program. Results shall be reported in accordance with the schedule and format proposed by the Research Sponsor.
APPENDIX II

GLOSSARY OF TERMINOLOGY
Definition of Terms

Introduction

This Appendix contains definitions of terms which are used in this report but not commonly found in standard references. A lack of common, standardized terminology in the industry is evidenced by the literature. As another step toward a possible future standardization of terminology in the South, the following basic definitions are offered. These definitions are an updated version of the only published definitions available from previous research work in pulpwood harvesting in the South (19, 20, 21). The justification of these definitions is identical to so many other definitions of forestry; they are justified by their practical workability.

Bucking

Bucking is the process of dividing (normally sawing) the merchantable stem into shorter lengths. Bucking begins when the saw comes into contact with the tree and ends when the tree is cut into shorter lengths. Most trees are bucked at the stump with a chain saw. However, if skidding is accomplished, bucking is normally done at a concentration point with either a chain saw, wheel saw, or a hydraulic shear. The product of the bucking function is a pulpwood stick or bolt.
Concentration Yard

A place, generally located beside a railroad or navigable water, to which producers bring truck loads of pulpwood. The concentration yard is operated by a dealer who ships the pulpwood in volume, by rail or barge, to a mill.

Cord

A cord of pulpwood is defined as 128 cubic feet of stacked, rough roundwood.

Dealer

The middle man between the producer and the mill is the dealer. He generally operates a concentration yard for barge or railway shipment of pulpwood to the mill. A dealer may be an independent entrepreneur or employed by a single company.

Felling

Felling is the process of severing a standing tree from the stump with the trunk subsequently falling to the ground. Felling begins when the felling instrument contacts the standing tree and ends when the tree is lying on the ground.

Sometimes, when a tree is falling to the ground, it may become wedged against other trees. The time required to dislodge this tree, plus the time to fall to the ground, is included in felling time. Felling also includes the time necessary to walk from one tree to another for the purpose of felling.
Harvester
See Producer

Hauling

Hauling is the act of transporting pulpwood sticks, multiple stick lengths, or tree lengths from the loading site in the woods to a mill or woodyard. Hauling begins when the primary hauling vehicle leaves the loading site and ends when it returns. Most pulpwood is hauled from the loading site in the woods to a point of sale. The majority of pulpwood is hauled in stick form. Pulpwood is usually transported on a single or double axle truck in the 1-1/2 to 2-1/2 ton class. Trucks in this class have an average capacity of about 2-1/2 to 4 cords. The mills and woodyards, whether rail or barge, have mechanical unloading facilities.

Limbing

Limbing is the process of removing limbs from a felled tree. Limbing begins when the ax, saw, or other limbing instrument comes in contact with the first limb and ends when the worker ceases removing limbs from those trees to be limbed. Limbing is usually accomplished immediately after felling and normally takes place at the stump. Occasionally, many of the limbs are stripped from the tree during the skidding operation. The crew member or members performing the limbing function may also perform other harvesting operations in conjunction with limbing. Limbing also includes removing the unmerchantable top from the tree.
Loading

Loading is the process of placing pulpwood, in the form of sticks, multiple stick lengths, or tree lengths on a hauling vehicle. Loading begins when the worker or mechanical loader grasps the first stick or log to be loaded, and ends when the hauling vehicle is loaded to the desired level. If a binder or chain or cable is utilized, the loading time includes the time for securing it. When limbing, measuring, and bucking are performed at the stump, the wood is normally loaded at the stump also. If skidding is employed, loading normally takes place at a prepared landing following the bucking function.

Log

A tree segment suitable for subsequent processing into lumber, pulpwood, or other wood products.

Measuring

Measuring is the process of apportioning the merchantable stem into segments of specified length for the purpose of bucking. Measuring begins when the worker commences apportioning the tree into desired lengths and ends when the tree to be measured has been segmented. Measuring is customarily performed with the aid of a measuring device, often a small tree or sapling cut to a desired length. The worker places the measuring stick on the tree to indicate the desired length and an ax or saw is used to indicate the point of cut for that segment. Limbing and meas-
uring, when done at the stump, are normally accomplished by one worker. However, occasionally the worker performing the measuring will work as a team with the feller, standing by or rough stacking previously cut bolts while the tree is felled, then holding the measuring device as a guide to the feller who bucks each tree immediately following felling. If measuring is not accomplished at the stump, it takes place after skidding and prior to bucking at a prepared landing or concentration point. In some areas, the measuring function is not accomplished. If measuring is not performed, the worker will use his experience to estimate where the tree should be bucked.

**Merchantable Stem**

The merchantable stem is that portion of the tree that can be utilized for limber, pulpwood, or other wood products.

**Mill**

Any industrial plant converting wood into woodpulp.

**Prehauling**

Prehauling is an intermediate hauling operation in which the stick, bundle, or load is not in contact with the ground. The load is usually hauled on a secondary hauling vehicle such as a pallet, cart, etc., and is normally pulled by a crawler or rubber-tired tractor. However, where poor terrain conditions exist, prehauling may be performed by utilizing the primary hauling vehicle to carry a partial load.
Producer

A producer is an individual who manages a pulpwood harvesting crew and sells his wood either directly to the mill or to a pulpwood dealer. The producer is normally the individual who organizes a pulpwood crew, receives payment for the wood produced, and pays the crew. In addition to selling his wood to the mill or a pulpwood dealer, he may also sell it at the roadside or in the woods to an individual primarily engaged in hauling.

A producer and his crew may be classified as either full-time or part-time. A full-time producer manages a crew whose normal occupation is pulpwood harvesting. A full-time crew, barring bad weather, lack of stumpage, or equipment failure, will harvest pulpwood most of the time. The part-time producer and the part-time crew will harvest pulpwood as a secondary occupation, turning to pulpwood harvesting when their normal means of livelihood is not available. For instance, farmers who cut pulpwood in the off-season are considered part-time producers and their crews part-time crews. It should be noted that the definition of a part-time and full-time producer is given in terms of the orientation of the crew rather than the producer himself. That is, even though a producer is engaged in another business most of the time, if his crew works full-time, he is considered a full-time producer.
Pulpwood

Wood cut or prepared primarily for manufacture into woodpulp.

Pulpwood Harvesting Crew

A pulpwood harvesting crew is a group of men organized for the purpose of cutting and/or transporting pulpwood to a pulpwood concentration yard.

Pulpwood Stick or Bolt

A segment of a tree cut to specifications prescribed by a pulpwood buyer. The pulpwood stick or bolt is usually between four and eight feet in length. The pulpwood buyer's specifications regarding wood length normally depend on transportation, pulp-mill, and pulpwood-yard equipment limitations.

Skidding

Skidding is the process of dragging tree lengths, logs, multiple stick lengths, or pulpwood sticks from the stump to a landing or concentration point, part of the tree being in contact with the ground. Skidding begins when the animal or machine and the operator leave the concentration point to skid the first tree, and ends when they return with the last tree to be skidded and it is unhitched from the animal or machine.

Slash

The residue of the harvesting operation, generally limbs and tops.
Stumpage

A tract of land with trees designated for harvesting.

Top

A top is that part of the tree above the minimum diameter of merchantable stem.

Topping

An operation consisting of the severing of the unmerchantable part of the stem from the merchantable stem—generally performed concurrent with limbing.

Tree Length

An entire tree, with the exception of the unmerchantable top and limbs, suitable for lumber, pulpwood or other wood products.

Yard or Woodyard

See Concentration Yard
APPENDIX III

THE PULPWOOD HARVESTING MODEL
A SIMULATION OF SHORTWOOD PULPWOOD HARVESTING SYSTEMS

DATA FUNCTIONS AND SYSTEM VARIABLE DEFINITIONS

1. FUNCTION P9 C2 TIME FOR PLAN MOVE CUT BLOCK
   \[ a \times 50 \]
2. FUNCTION V2 C2 TIME TO B.L.T
   \[ b \times 100 \]
3. FUNCTION V3 C2 TIME TO LIMB AND TOP
   \[ c \times 100 \]
4. FUNCTION V4 C2 TIME TO BUCK
   \[ d \times 100 \]
5. FUNCTION V5 C2 TOTAL TIME TO HAND LOAD STUMP TO STUMP
   \[ e \times 100 \]
6. FUNCTION V6 C2 TIME FOR ONE WAY HAUL
   \[ f \times 100 \]
7. FUNCTION RN1 D3 LIMP FACTOR
8. FUNCTION P3 C7 LENGTH OF MERCHANTABLE STEM
   \[ g \times 25 \]
9. FUNCTION RN1 C2 NORM TIME TO LIMB AND TOP
   \[ h \times 10 \]
10. FUNCTION RN1 C6 TIME TO MOVE TRUCK STUMP TO STUMP
    \[ i \times 0.7 \]
11. FUNCTION P3 C8 \[ j \times 4 \]
12. FUNCTION P5 C4 TIME TO STACK BOLTS
    \[ k \times 4 \]
13. FUNCTION RN1 C7 DBH DISTRIBUTION
    \[ l \times 0.1 \]
14. FUNCTION RN1 C10 PAVED ROAD DISTANCE 120 MPH AVG.
    \[ m \times 25 \]
15. FUNCTION RN1 C6 DIRT ROAD DISTANCE 3 MPH AVG.
    \[ n \times 0.25 \]
16. FUNCTION RN1 C3 DISTANCE BETWEEN TREES
    \[ o \times 6.0 \]
17. FUNCTION RN1 D3 UNDERBRUSH FACTOR
    \[ p \times 0.0 \]
18. FUNCTION RN1 D4 TIME TAKEN TO LOAD ONE BOLT ON A PLET
    \[ q \times 1.0 \]
19. FUNCTION P5 C4 TIME TO LOAD BOLTS ON TRUCK MANUALLY
    \[ r \times 4.0 \]
20. FUNCTION RN1 C5 DELAY FUNCTION - FATIGUE PERSONAL MAINTENANCE ETC.
    \[ s \times 1.0 \]
21. FUNCTION FN22 C2 TIME FOR SKIDDRILL ONE TURN DRY SOIL
    \[ t \times 200 \]
FUNCTION RN1 C2 ONE WAY SKID DISTANCE IN FEET
*0 201 140 999
23 FUNCTION V12 C2 TOTAL SKID TIME
*0 0.0 200 210
26 FUNCTION RN1 C3 MACHINE LOADER CYCLE TIME--SIX BOLT LOAD PER CYCLE
*0 2 0.85 5 1.0 9
25 FUNCTION V14 C2 TOTAL TIME TO LOAD MECHANICAL
*0 0.0 150 150
26 FUNCTION RN1 C6 PRE-HAUL ONE WAY DISTANCE IN FEET
*0 200 0.15 600 0.4 9 1300
27 FUNCTION P9 C2 FELLER DELAY TIME
*0 0.0 70 70
28 FUNCTION RN1 C6 UNLOAD TIME AT MECHANIZED YARD (HALF TIME VALUES)
*0 210 0.6 66 0.6 90 0.9 108 1.0 135
29 FUNCTION V15 C2 TIME TO LOAD PALLET
*0 0.0 250 250
30 FUNCTION V16 C2 TIME TO PRE-HAUL
*0 0.0 60 60
1 VARIABLE V8*P1+FN10 TIME FOR PLAN MOVE CUT BLOCK
2 VARIABLE V3*V4 TIME FOR B L T
3 VARIABLE FN8*FN7 TIME FOR LIMB AND TOP
4 VARIABLE FN10*P5 TIME TO BUCK A TREE
5 VARIABLE FN19*FN9 TOTAL TIME TO MANUAL LOAD
6 VARIABLE P15*K12+P14*K12+P16 TRANSPORT AND UNLOAD TIME
7 VARIABLE P4*K5 BOLTS PER STEM
8 VARIABLE P2*K5+P5*K2 HELP VI COMPUTE
9 VARIABLE P7*P2*P4*K1364/K1000000 COMPUTE STEM VOLUME
10 VARIABLE FN21+P8 TIME FOR ONE SKIDDER TURN (PRODUCTIVE TIME)
11 VARIABLE P3*K5 HELPS V9
12 VARIABLE P10*K35/K100+P10 TOTAL TIME FOR SKIDDER OPERATION
13 VARIABLE P5*K6 NO. OF LOADER CYCLES TO LOAD A SKID LOAD
14 VARIABLE V13*FN24 TOTAL MACHINE LOAD TIME
15 VARIABLE FN18*P5 PALLET LOAD TIME
*
*
FOREST SIMULATION -- START OF SIMULATION PROGRAM
*
LOC. NAME--------X-------Y-------Z--------SEL--------NBA--------NBK--------MEAN--------MOD--------REMARKS--------}
1 GENERATE 01 LE K5 3
2 COMPARE 01 LE K5 4
3 ASSIGN 1 K1 4 CLEAR CUT OPER
4 ASSIGN 2 FN16 5 TREE SPACING
5 ASSIGN 3 FN13 6
6 ASSIGN 4 FN11 7 USEABLE STEM
7 ASSIGN 5 V7 8 BOLTS PER STEM
8 ASSIGN 6 K4 9 TREE TRANSACT.
9 ASSIGN 7 V12 10 HELP V9
10 ASSIGN 8 FN17 11 BRUSH FACTOR
11 ASSIGN 9 V1 12 PMC TIME BK 20
12 ASSIGN 12 K1 13 TRANSACT = LOG
13 ASSIGN 17 V9 19 VOLUME OF STEM
14 QUEUE 1 20 WAITING FELL
THE FOLLOWING BLOCKS (20, 30, 50, 60, 70) ARE SHOWN WITH THEIR BUFFER BLOCKS (80, 81, 82) READY TO START THE STUMP TO STUMP HARVESTING SYSTEM SIMULATION.

START OF MOVE, PLAN, AND CUT SIMULATION (BLOCK 20)

20 HOLD 1 80 1 FN1: PLAN MOVE FELL
20 QUEUE 2 30

START OF BUCK, LIMB, AND TOP SIMULATION (BLOCK 30)

30 HOLD 2 81 1 FN2: BKT
30 QUEUE 3 50

START OF STACK SIMULATION (BLOCK 50)

50 HOLD 2 82 1 FN12: STACK ROUGH
50 QUEUE 4 60

START OF MANUAL LOADING SIMULATION (BLOCK 60)

1 CAPACITY 260 MAX TRUCK LOAD (VOLUME OF SOLID WOOD)
60 COMPARE R1 GE K4C 61 IS ROOM THERE
61 ENTER 1 P17 62 TAKE UP SPACE
62 HOLD 4 63 1 FN5: LOAD MANUALLY
63 SAVEX 4+ +12 64 COUNT TREES
64 SAVEX 5+ P5 BOTH 65 66 COUNT BOLTS
65 COMPARE R1 GE K4C 99 IS LOAD READY
66 PRINT 4 5 67 LOAD STATS
67 SAVEX 4 K0 58 SET TREE COUNT
68 SAVEX 5 K0 69 SET BOLT COUNT
69 LEAVE 1 K220 70 TRUCK HAS LOAD

START OF HAULING SIMULATION (BLOCK 70)

70 ASSIGN 14 FN14 71 PAVED ROAD DIST
71 ASSIGN 15 FN15 72 DIRT ROAD DIST
72 ASSIGN 16 FN28 73 UNLOAD TIME
5 TABLE J1A 0 180 2D TIME IN BETWEEN LOADS
73 TABULATE 5 74
74 INTERRUPT 4 75 TRANSPORT
3 TABLE P14
3 TABLE P15 1 1 60 HAUL DISTANCE TABLE
75 TABULATE 3 100
BEGIN LIST OF HARVESTING OPERATION ALTERNATIVES

THE FOLLOWING BLOCKS (31, 32, 40, 61) ARE UNIQUE TO THE MECHANIZED HARVESTING SYSTEM SIMULATION

START OF LIMB AND TOP SIMULATION (BLOCK 31)

31 HOLD 2 83 1 FN3 LIMB AND TOP

START OF BUCK FUNCTION SIMULATION (BLOCK 32)

32 HOLD 6 86 1 FN4 BUCK FUNCTION
START OF SKIDDER OPERATION SIMULATION (BLOCK 40)

2 CAPACITY 65 MAX SKID LOAD OF SOLID WOOD VOLUME
40 ENTER 2 P7 41 1 START SKID OP.
41 SAVEX 1+ P5 42 ADD TREE BOLTS
42 SAVEX 2+ P7 43 ADD TREE VOLUME
43 SAVEX 3+ P12 BOTH 49 NO. STEMS SKID
44 COMPARE R2 LE 45 YES--SKID LOAD
45 ASSIGN 5 X1 46 BOLTS PER TURN
46 ASSIGN 7 X2 47 VOLUME OF TURN
47 ASSIGN 12 X3 48 LOGS PER TURN
48 PRINT 1 3 21 SKIPPER OUTPUT
21 ASSIGN 10 V10 22 TURN TIME
22 SAVEX 1 K0 23 RESET BOLTS
23 SAVEX 2 K0 24 RESET VOLUME
24 SAVEX 3 K0 49 RESET LOGS
49 LEAVE 2 P7 34 1 FN23 SKIDDING TIME

START OF MECHANICAL LOADING SIMULATION (BLOCK 61)

62 COMPARE P7 LE R1 63 IS THERE ROOM
63 ENTER 1 P7 64 YES
64 HOLD 4 P7 30TH 65 99 1 FN25 LOAD UP TRUCK
65 COMPARE S1 GE X220 66 IS TRUCK FULL
66 LEAVE 1 X220 70 TRUCK IS FULL

THE FOLLOWING BLOCKS (51,52,62) ARE UNIQUE TO
THE UNIT LOAD CONCEPT OF HARVESTING

START PALLET LOADING SIMULATION (BLOCK 51)

51 HOLD 3 140 MAX PALLET VOLUME OF SOLID WOOD
53 ENTER 3 P7 54 OCCUPY SPACE
54 SAVEX 6+ P7 55 VOLUME OF STEM
55 SAVEX 7+ P12 56 NO. OF STEMS
56 SAVEX 8+ P5 BOTH 57 99 NO. OF BOLTS
57 COMPARE R3 LE X31 58 YES--FULL LOAD
58 ASSIGN 5 X8 59 VOLUME LOADED
59 ASSIGN 7 K109 34 NO. OF TREE CUT
34 ASSIGN 12 X7 35 VOLUME LOADED
35 PRINT 6 8 36 STAT PRINT OUT
36 SAVEX 6 K0 37 RESET VOLUME
37 SAVEX 7 K0 38 RESET STEMS
38 SAVEX 8 K0 39 RESET BOLTS
39 LEAVE 3 K109 87 END PALLET SIM
**START PRE-HAUL SIMULATION (BLOCK 52)**

52 HOLD 7 89 2 FN30 PRE-HAUL PALET

**START PALLET TRANSFER OPERATION (BLOCK 62)**

4 CAPACITY 5 MAX NUMBER OF PALLETS TO LOAD ON TRUCK
62 ENTER 4 BOTH 63 95 TAKE UP SPACE
63 COMPARE 54 E K5 64 GOT 5 PALLETS
64 HOLD 4 65 180 60 WINCH ON TRUCK
65 LEAVE 4 K5 70 PALLETS GONE

**PROGRAM BUFFER BLOCKS**

* BETWEEN EACH HARVESTING OPERATION BLOCK THE PROGRAM REQUIRES THAT A BUFFER BLOCK BE PLACED. IN COLUMNS 57 TO 8C OF EACH BUFFER BLOCK A COMMENT STATING WHICH BLOCKS THIS BUFFER GOES INBETWEEN.

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APPENDIX IV

A SAMPLE PROGRAM OF THE
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### QUEUE

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**Future Random Number Seed is (Octal): 072103766775**
The use of a 45 degree function provides a simple method to obtain one-to-one correspondence of variables. This is often required in order to circumvent program restrictions. The following table lists the program functions which use the 45 degree function for this purpose.

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FN 7. Limb Factor

FN 8. Time to Limb and Top
FN 9. Time to Move Truck Stump-to-Stump

FN 10. Time to Sever Stem
Data for 30 year old Virginia Pine on Site Index 65 at 100% density

FN 11. Merchantable Stem Length

FN 12. Time to Stack Bolts
FN 13. D.B.H. Distribution

Data for 30 year old Virginia Pine on Site Index 65 at 100% density

FN 14. Paved Road Distance
FN 15. Dirt Road Distance

FN 16. Tree Spacing
FN 17. Underbrush Factor

FN 18. Load Time per Bolt for Pallet
FN 20. Delay Function Time Distribution

FN 19. Time per Bolt to Load Truck
Time Units

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Wet Soil

Dry Soil

Distance (x 100 ft.)

"Normal"

Equi-probable

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FN 21. Skidding Time per Turn

FN 22. One Way Skid Distance
FN 24. Load Time per Machine Cycle

FN 26. Pre-haul Distance One Way
Time Units (x 10)

FN 28. Truck Unloading Time
LITERATURE CITED


12. Dyson, P.J. and Lawrence, D., Estimating Logging Cost Based on Rate of Output, Georgia Forest Research Paper No. 48 (September 1967).


55. Taras, M.A., *Buying Pulpwood by Weight as Compared to Volume Measure*, U.S. Southeastern Forest Experiment Station Reports, No. 74 (1956).


OTHER REFERENCES


28. Langdon, O.G., Yield of Unmanaged Slash Pine Stands in South Florida, U.S. Southeastern Forest Experiment Station Reports, No. 123.


