A METHOD OF DATA COLLECTION FOR THE EVALUATION OF FOREST HARVESTING SYSTEMS

by

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Dissertation submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Forestry

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December, 1984
Blacksburg, Virginia

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(ABSTRACT)

A unified international method to capture, record, and report the information necessary for documenting the mechanical performance of harvesting machines and systems under specified conditions is presented. It provides a data collection method as a basis for evaluation of systems accross international boundaries for better selection of machines, prior to bearing the expense of purchasing the system. An in depth study of a prototype skidder on steep terrain was conducted to test the practicality of the method. The study resulted in some modification of the

been recieved indicating support and suggesting minimal changes. The recomendations of other reviewers will be incorporated in the final Field Manual. A microcomputer program for filing and editing the data collected in the field will be developed.

ACKNOWLEDGEMENTS

During my graduate work I was very fortunate to get to know and work with my committee members. My thanks and appreciations are extended to every one of them for their patience and guidance, in particular Drs. W. B. Stuart and T. A. Walbridge, Jr., for their support and assistance which were carried beyond academia. They were always ready to help me and my family in any way they could. I wish to express my sincere gratitute to Dr. Walbridge for his extra generousity and frienship which is invaluable gain for me. I would like to thank Dr. R. M. Shaffer who served as a committee member while Dr. Stuart was gone to New Zealand.

I wish to thank Mr. Bennett and all his crew members who were the most cooperative while collecting data and testing the original draft of the forms. Also, thanks to the United States Forest Service officers at Roanoke, New Castle, and Blacksburg for their assistance and making available the information about the harvesting area.

Finally, with love and deep appreciation, a special thanks goes to Maryam and Hooramack for their continuous love, understanding, support, and always encouragement.

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INTRODUCTION

In timber harvesting, like in any other industry, thesystem concept plays an essential roll. Generally, a system can be thought of as a group of interrelated components joined together to contribute to the achievement of a specified purpose or objective. Timber harvesting is the process of felling trees and preparing them for movement from the stump to their end-use points and includes identifiable, interrelated characteristics such as raw material (input), equipment, procedures (methods), information, control, planning, and people. Each one of these characteristics has its own place and importance which must be studied carefully.

In forest harvesting, trees are the basic raw material. During harvesting trees of all sizes are felled and processed in different product forms. Some are produced as pulpwood bolts, sawlogs and peeler logs, or some may be produced as tree lengths, whole trees, segments of trees or whole tree chips. Species and forms of raw materials produced are very important in the selection of equipment as well as in planning.

Equipment used in harvesting systems includes heavy machines and devices or tools that contribute to a specified end-result.

Methods are the ways which may be selected to pursue the management goals. They are often a combination of techniques and machines best suited to provide the most efficient output.

To pursue the objectives, and select the right equipment, there must be enough factual information about the raw material, the environment, and all other related subjects to provide a good basis for sound planning and achieve the stated goals.

Information about contributing factors is essential for planning and system development. Factors affecting the system must be isolated and studied to assess their effect. Proper classification and a clear presentation of information are the keys to sound work analysis. The analyst can waste his or her time and fail to present solutions to problems if he or she is just blindly groping for answers (Johnson and Ogilvie, 1972). In forestry, such information comprises a wide range of factors from climate and geology to equipment and people characteristics. Some of these factors have great effect on output while others have little impact. Some factors may be considered highly influential in one area and environment, while these very same factors may have little or no influence in other areas. The effects of these variables must be researched and cumulative results of the studies must be used as determining factors for developing and using harvesting systems efficiently.

The system must be flexible enough to withstand and adapt to planned, predicted, and unforeseen changes in the environment or internal conditions. There must be a constant check and control on these interactions in any system, because of interaction between man, machine, and procedures.

Planning, in a general sense, is the overall strategy of selecting and distributing the equipment and appointing the personnel to specified jobs or operations as well as specifying a time table and the sequence of steps to be followed.

People are very important, not only as planners and managers, but also as operators and system developers. The man-machine relation is important and must be studied carefully. Attention to these relationships has increased in recent years. Ergonomics or human factors has become increasingly important and successful in systems design. Much more work needs to be done, especially in the harvesting area.

The above mentioned information can be so straight forward that it may be obtained by using a simple process like recording the related observed elements, or it may be so complex as to demand careful design of statistical procedures and analyses. But, in any case, data should be collected in an objective manner with a clear understanding of the expected results.

Like many other industries, work study in forestry, has been employed and used effectively in many different ways. Scientifically conducted, work study can function as a technique to obtain facts which can be used to improve the operation. In other words, work study may be regarded as a procedure for determining the truth and improving the activities of existing manpower and equipment. In addition, work study has proven to be a powerful tool for achieving higher efficiencies under existing circumstances.

The purpose of work study is to assist management to obtain the optimum use of all available resources (human and materials) allocated to a specified task. To achieve this objective, consideration must be given to the most effective use of equipment, people and evaluating human work. "Time and motion study" is widely used in forest harvesting where a great amount of investment is involved. It is used as a tool to provide detailed information on each activity and provides a basis for statistical analysis for production and cost prediction.

Rapid expansion in communication and trade across international boundaries has made it possible to use data collection and information compiled for local management practices as a basis for evaluating the use of the system in other areas and other countries. The advantage of having enough information and strong evidence of system applicability to other areas, particularly prior to heavy investment, is quite obvious. It is not good economic practice to purchase a system and put it in place to see if it suits the conditions, and/or whether it is capable of providing the expected services. Therefore, having a scientific productivity evaluation, which will provide enough information about a system and its performance in different conditions, will aid in deciding if the system can be considered at all.

Harvesting research institutions have collectively published a great deal of information concerning their studies and tests. Many of them have laid down the basis for evaluating systems and methods involved in harvesting. However, a shortcomming common to all of them is that the methodology and test conditions are conducted locally and are sometimes unique to that area. To overcome this problem, a unified method of data collection which can be applied world wide is proposed. The ability to capture all details and factors affecting the performance of a system would provide a good basis for comparisons among promising systems in different conditions and locations. This information should also be of value in the selection of the best alternative for a particular solution.

Generally, the high expense of field work for time study and information collection prohibits devoting long periods of time to this process. Therefore, relatively short periods of time (about 1 or 2 weeks) are usually spent on field work. The information and data obtained by this method is useful for determining machine and system productivity and documenting performance. However, these short term studies are not adequate for the determination of machine availability and utilization. This is a common problem with conventional data collection techniques and may be overcome by obtaining more data from different locations and under different conditions or another technique like work sampling or long term service recorder data.

During the late 1960's and early 1970's a cooperative testing procedure was developed by the American Pulpwood Association-Harvesting Research Project (APA-HRP) for use in the Eastern United States. The procedure prescribed the techniques used to collect information and data for harvesting analysis. It was a comprehensive documentation of detailed information and the techniques used to capture the effects of the environmental, mechanical, personnel, operational, and economic factors affecting the system.

This early cooperative testing procedure was the basis of the present research. The procedure was redesigned to allow for international communication and application and to include advances made in harvesting and related science during the past dacade.

Thus the objectives of this research are as follows:

1. To expand, modify, and adapt the APA-HRP Cooperative Testing approach and develop a data collection method to serve as an international standard which can be used around the world for the evaluation of harvesting machines and systems.
2. To test the adequacy of the data collection method for international use by requesting an assessment by member countries of the International Energy Agency (IEA), and using the method to conduct a time study of a machine newly incorporated into a harvesting system in the Appalachian Mountains.

LITERATURE REVIEW

The emphasis of the literature review was to collect information directly related to the analysis of harvesting machines and systems. Special attention was given to the latest publications concerning machine evaluation procedures. This review was mainly concerned with the identification of factors and variables believed to be influential in the outcome of the existing studies and to show the differences between the data collection approaches used. Thus, the factors considered important to investigators are summarized rather than reporting findings of the studies themselves.

The review is divided into three sections: Research Studies Conducted in the United States; Publications of International Organizations; and Selected Literature from Other Countries.

Research Studies Conducted In The Untied States

One of the early efforts made to develop detailed cost and productivity calculations in forest harvesting was by Battelle Memorial Institute during early 1960's. The project was sponsored by the American Pulpwood Association (APA) and was designed to define and improve the technology of pulpwood harvesting in the Southeastern United States. Harvesting costs, weather, labor supply, and machinery evaluation were considered as the most important factors. The study used a random sampling method and involved 76 wood producers. The data were collected using "gross time studies" with wrist watches and recording the total elapsed time to accomplish each of the major functions and crew activities. Regression analyses were conducted to produce prediction equations.

The factors considered in this study were: terrain, underbrush, stumpage, roads, supervision, crew proficiency and experience, and weather. The two variables recorded for terrain were slope and ground conditions. Ground conditions were specified as swampy, boggy, slippery-muddy, dry-sandy, and dry-firm. Underbrush was specified as heavy, medium, and negligible. Three variables were considered for stumpage. These variables were cords/acre, tree characteristics (average height and range, average DBH, and butt diameter), and limbs (characterized by many, moderate, and negligible). Roads were evaluated based on class and distance. Road classes were woods roads, unimproved forest roads, graded, and paved. Road distance was mileage of each road class. Supervision was recorded depending on the amount of time supervisor was present and ranged from 0-100%. The crews were evaluated as not aggressive, average, and aggressive. For weather effect, conditions on the day of observation, and the previous day were recorded.

Worthington (1966) analyzed and discussed the differences involved in using three skidding methods for thinning of young Douglas-fir and western hemlock in central Washington. He presented the effects of volume thinned per acre and average DBH of harvested trees on total labor requirments. The factors considered important were: age; species and composition; volume /acre; average DBH; type of thinning; product forms; total thinning; date of operations; number of crew members; road spacing; average skidding distance; operators experience; and, one way trucking distance.

McDonald et al (1969) in a study to compare logging costs and cutting methods in mixed conifer stands in California listed the factors influencing cost and production as : species and mix ratio; volume/acre; average tree size, amount of underbrush, amount of downtimber, soil, slope, season of the year, and silvicultural requirements.

Schillings (1969) compared relative operating costs of crawler tractors and developed a method based on skidding distance, terrain type, slope, and operator efficiency to estimate costs. Factors required were crawler size, crew combinations, and operating conditions. With regard to stand factors, only volume/log had to be known. Terrain was classified into three categories of:

1. Soil firm, dry- Little slash, downtimber, stumps, rocks; mostly established skidding trails.
2. Soil moderately wet, soft- Moderate slash, downtimber, stumps, rocks; mostly new and old skidding trails.
3. Soil muddy, loose- Heavy slash, downtimber, stumps, rocks; mostly new skidding trials.

Slope was categorized as: 15% or less; between 15% to 30%; and, over 30%. Other slopes could be interpolated within each category. Tractor operator efficiency was rated as 134% (highest); 100% (average); and, 67% (lowest) based on comparisons among many operators and again with the possibility of interpolating within each group.

The Harvesting Research Project (HRP) of the American Pulpwood Association (APA) initiated a program to provide a practical technique for the study, analysis, and reporting of the productive and financial aspects of selected harvesting machines and systems. This program which was titled the "Cooperative Testing Program" resulted in a series of studies of operations in the Southeast. An example of the procedure and factors considered in these studies can be found in their report on prelogging (Curtin and Bunker, 1971). Two TH-100 Thinner-Harvesters and one Franklin 170 Pack-A-Back Prehauler were the components of the system under investigation. The report contains a detailed description of system specification and all support equipment, a harvesting procedure, a product table, description of personnel, timing procedure, and decription of environment. The environmental factors are the harvesting chance (the site location, soil, trafficability, age of stand, origin of stand, species composition, number of merchantable stems/ acre, DBH, number of stems harvested, volume/acre harvested, number of trees/acre harvested, diameter distribution of species, brush intensity, walking quotient, ground roughness, slope, and ground conditions), and weather (rain, temperature, wind velocity and frequency). Attention was also paid to human factors characteristics of the system. The ergonomic consideration included operator safety, comfort, and serviceability for which inspection was made on the cab (location, mounting and alighting, and foot steps), machine stability (turnover), accident hazards, doors and emergency exits, seat (horizontal and vertical adjustment capabilities, and seat belt), gauges and controls locations, operator visibility, operator comfort in different positions, air conditioner, convenince of access and reach of fuel tank, hydraulic oil reservoir, and filters. Machine productivity and availability was calculated. A record of repairs and time required to fix them was maintained. Attention was also paid to keep the personnel, machine and harvesting site the same. Comparison of productivity before and after some modification on the machine were made. For analysis, Forest Models were installed and function timing was conducted to provide regression equations for economic analysis and production rates.

Bradley and Biltonen (1973) examined the productivity of selected aspen pulpwood operation in northern Minnesota. In their studies they included the following factors:

1. Stand- Volume/acre, trees/acre, basal area/acre, tree spacing, brush density (both qualitative and quantitative).
2. Terrain- Slopes, ground roughness (qualitative).
3. Climate- Snow depth, temperature, wind, precipitation.

4. Operating- Skidding distance, logger (differences in their productivity)

Gardner and Hartsog (1973) studied the costs and production of logging Lodgepole pine in Wyoming using a feller- buncher, skidders, and a portable chipper. The factors considered were: size of the area; species composition; type of cut; merchantable volume and weight-scale; nonmerchantable chip volume; number of merchantable pieces; number of nonmerchantable pieces; and average size. Machines specifications were included in their report.

Aulerich *et al* (1974) studied thinning young-growth timber (less than 20 inch DBH) by skyline and tractor systems in Oregon. The reported factors were: species and composition; age; slope; treatment; site and stand damage; crew size; season; site productivity; average DBH; average stand volume/acre; number of merchantable stems removed; product type; volume of each product type produced; product grades; number of trees cut; average volume/log; average volume/tree; road and skyline settings spacings; and, crew size.

Biltonen, *et al* (1976) investigated the methods and economics of mechanized thinning of Northern hardwood pole stands. In this study, factors of importance were: area to be harvested, species and mix ratio, soil and moisture, topography, volume/acre, number of trees/acre, basal area/acre, DBH and its range, age origin, method of cut, weather conditions (rain, snow, and temperature), brush conditions, the landing and its condition, and residual damage.

Sampson and Donnelly (1977) considered factors affecting the productivity of skidders in selection cuts of Southwestern Ponderosa Pine. Volume/acre, volume/tree, uphill and downhill skid distance, slope, defect deductions, number of pieces/acre to be skidded, density of residual stand, soil, surface condition, and operator effeciency were reported.

Host and Schlieter (1978) reported the results of a study of low-cost harvesting systems for intensive utilization of small-stem Lodgepole pine stands. Factors included were: location and its elevation; slopes; age; species and composition; average unit cut; average tree sizes; volume/unit of the cutting area; DBH; average tree volume; average volume of dead trees; volume/acre; and, volume of down material.

Goulet et al (1979) reviewing the state of the art of harvesting simulation models concluded that many forest harvesting simulations have been developed in North America.

Based on the developer's point of view, and whether the model simulates only one phase or the whole operation from stump to mill, the essential elements for constituting the model, differ from one model to another. Most models include stand factors. Associated stand factors considered in simulation models are tree location, tree volume, DBH, merchantable height, tree density, total number of trees harversted, species, area to be harvested, slope, and terrain. Some models have considered as few as two factors, while others have used all stand factors listed above.

Winsauer (1980), wrote a computer program and compiled documentation for the simulation of a tracked feller-buncher. She considered the following factors to be influential and important for development of the model: machine's operating characteristics; stand and the type of harvest to be carried out; average stand diameter; average stand volume; average tree height; average trees/acre; strip length; distance between strips; wood density; actual tree diameters; and, tree volume. The simulation program did not account for ground conditions, climate, and ergonomics.

Hoffman (1980) in studying partial cutting operations in an effort to develop techniques which minimize damage to the stand and require less capitial and energy than the present methods, reported the effective factors as number of dead trees to be removed, number of large shrubs/acre, terrain conditions, soil, skidding distance, slope and road spacing.

Johnson et al (1980) in a mechanized thinning study conduted in Northern hardwood pole size stands, considered the effective factors as location, stand type, species and composition, number of trees/acre, basal area, residual basal area, number of routes and their spacing distances.

Wiksten and Prins (1980) working on a project for Energy from Forest (ENFOR) provided an estimate of performance and costs for the retrieval, harvest and delivery of forest biomass at the energy conversion plant. The characteristics of the biomass available for retrieval after conventional operations and the biomass available for harvest in low grade hardwood stands are listed. These characteristics are those that have a direct and indirect influence on production. The list includes species composition, total original volume of stand, total volume of logging residue, number of pieces per hectare, average volume per piece, biomass (oven dry weight) per hectare, volume left after logging, volume of standing trees after logging, volume of merchantable wood removed in logging, original percent volume of merchantable wood, average volume of residue trees, average volume of logging residue, biomass on the ground (oven dry weight per hectare), biomass standing trees (oven dry weight per kilogram), total residual biomass (oven dry weight per hectare), type of logging, cover type, average length of pieces, average distance between pieces, average diameter of pieces, average volume per piece, average distance between trees, average height per tree, average DBH, and average weight of green trees.

Massey and McCollum (1981) conducted a study to determine the economic feasibility of harvesting whole-tree chips for energy in the South from a typical residual stand. The stand factors investigated included location, site, topography, soil, species and composition, and type of product.

Stuart et al (1981) studied the economics of incorporating residual recovery equipment into existing harvesting systems. Using a computer simulation in pine plantations and mixed pine hardwood and upland hardwood stands, the effect of moving from conventional products to total energy wood harvests were assessed. Changes in both operating costs and capital used were the basis for the measurement of the effects. Since the computer simulation used was the Harvesting Analysis Technique (HAT), the factors considered are those mentioned earlier in the Goulet et al study.

Publications From International Organizations

The forest Logging and Transport Branch of the Forestry Department of Food and Agricultual Organization (FAO), has been involved in forest harvesting as well as other forestry activities throughout the world.

FAO has published a series of forestry papers, among them "Planning Forest Roads and Harvesting Systems, 1977". In this publication general considerations for documenting information used in evaluating harvesting systems have been categorized by the different factors which have been defined and classified as:

1. Terrain and soil - The "IUFRO" proposal for an international system of terrain classification is generally used. This classification includes:

   a) Steepness- Refers to major slopes, longer than 50 meters. Slopes shorter than 50 meters should thus be disregarded.

   b) Ground roughness- Refers to the occurance of obstacles of more than 50 centimeters of height or depth. The classification of smooth, rough and very rough is somewhat arbitrary, but in very rough the average distance between obstacles should be less than 3 meters.

   c) Capacity for traction/floatation- Cannot be quantified in a simple manner. In general "good" applies to friction soils and "bad" to cohesion siols. If possible, classification should be based on local experience from use of tractors, form and quantity of percipitation, season of operation, intensities of passage etc.

However, with regard to friction and cohesion soils, it is not clearly stated whether it is under wet or dry conditions. Certainly, the dry conditions will reverse the situation and friction soils will become "bad" and cohesion soils will become "good."

2. Forest stand- Species and composition, volume/hectare of harvest wood, DBH, product form, log sizes, the average number of merchantable trees/hectare, the ratio of non-merchantable trees that have to be felled and cast aside to merchantable trees felled and bunched, topography of the land, spacing or density/hectare of the feeder road, weight of product to be picked up by a worker (which will be decided upon by considering several climatic and human factors: temperature; altitude; body weight of the labor; and, nutrition).
3. Climatic conditions- Ambient temperature, relative humidity, rain, snow, and altitude.
4. Management and silviculture- Any restriction on logging, selective logging, natural regeneration or clear cutting, reforestation, and regulations concerning the soil and erosion, disposal of brush, tops and other debris.

5. Length or type of product- Log lengths and type of products specified.
6. Labor- Availability, experience, aptitude, attitude toward work and training, body weight, general health and nutrition, the work day, wage rates and fringe benefits, and motivating influences.
7. Mechanical equipment- The simplicity of the machine, the availability of service and replacement parts. ability to perform adequately on the terrain in the logging area, mechanical availability and utilization, and normal machine life.
8. Measuring wood production- The method of measuring wood production may affect the cost of harvesting and should be considered in this respect. Logs are usually meausred or scaled for one or more reasons:
   a) To pay pieceworkers and/or contractors;
   b) To pay government dues;
   c) To control production.

The International Union of Forest Research Organizations (IUFRO), has been the international body of scientific research and technology application in forestry. The "Terrain Classification For Forestry And Machines" and "Forest Harvesting Mechanization and Automation" which have been the themes for different symposiums are good examples of the attempts of IUFRO to develop standardized procedure of analyses. The IUFRO proceedings are valuable references. They contain a wealth of world wide information on harvesting mechanization by different nations and situations. A review of the presentations in the 1974 IUFRO symposium with a summary of factors considered important by investigators is set out below.

Jasson from Skogsarbeten of Sweden presented the conditions and mechanization of logging in Finland, Norway and Sweden. The conditions and mechanization of logging in these Nordic countries for nonmountainous lands is considered with effective factors being total area, expected timber crop, species composition, total cut/year, silviculture practices, type of product, wage levels, purchase price of machines, tree data (height, DBH, and volume), volume/hectare, stand density, age, variation in DBH, mean volume/tree, branchiness, terrain conditions (including ground bearing capacity, ground roughness, slope, snow and trafficability),and temperature.

Czereyski summarized the harvesting techniques in the German Democratic Republic, Hungary, and Poland. The factors mentioned are growing stock, species composition, area of harvesting, total removal, type of cut, product type, DBH, height, volume/tree, volume/hectare, terrain conditions (trafficability, ground roughness, slope, and snow), product form (full-tree, tree -length, log-length which is limited by road traffic regulations, and short-wood).

Rawan based on reports received from Eire, Federal Republic of Germany (West Germany), the Netherlands, Northern Ireland, Switzerland and Great Britain provided some general information on timber harvesting situations in Western Europe. The factors noted in this report are species and composition, area to harvest, silvicultural practices, production type, form of production, tree data (height, DBH, and volume), terrain conditions (bearing capacity, ground roughness, slope, and snow), wages, and machine costs.

Noefle from Switzerland discussed the Centeral European point of view on techniques for analysis, comparison, and choice of harvesting system. He stated that logging is seen as a subsystem of the forest enterprise. This enterprise is composed of many other subsystems such as marketing, timber growing, and administration. The forest enterprise also is influenced by a surrounding supersystem which can be a composition of law, politics, economy, society, technique, and nature subsystems. These can be used for defining the elements that belong to or influence harvesting systems and methods. Factors influencing the choice and efficiency of harvesting system can thus be defined and investigated as:

1. Stands: size of cutting unit, species composition, stability, dimension of trees (DBH, height), quality of trees (branchiness, taper), volume/acre, and type of cut.
2. Terrain : slope, bearing capacity, and accessibiltiy.
3. Opening-up: landing, standard and distance of the roads, skidding, and cable traces.
4. Factors of production (input): workers (capacity, qualification, and efficiency), machinery (type, availability, productivity, and ergonomics).
5. Timber market: demand for timber (dimension, quality, amount, time and place of delivery).
6. Environment: scenery, recreation, soil erosion, and water pollution.

Stuart and Walbridge from the United States presented another approach to tackle the problem of the evaluation and analysis of harvesting systems. This approach consists of a computer simulation program called the Harvesting Analysis Technique (HAT). Effective factors required to be recorded are terrain (bearing strength, tractive characteristics, roughness, slope, soil and moisture content), species composition, land ownership, tract size, tree location coordinates, diameter at groundline, DBH, bark thickness at groundline and breast height, merchantable height to a four-inch top diameter, crown width, tree form, volume, tree density, total number of trees harvested, average number of stems/acre, and clear bole length.

Horncastle from Canada considered a technique for analysis of comparisons and choice of harvesting systems. The purpose was to note qualitative and quantitative factors in the analysis of harvesting systems and presenting a simple procedure for comparing productivities and costs prior to more detailed investigations. These factors were:

1. Availability, capability and stability of people who will work with the system.
2. Availability of equipment from a manufacturer, the popularity of the machine, and availability of good service.
3. Silviculture factors including forest management recomendations for selecting harvesting systems, and effects of logging on the forest environment, erosion, fire, soil, nutrition and aesthetics.
4. Development possibility with regard to flexibility of the system to accomodate changes in product form and potential for further development.
5. Productivity and cost factors.

Almquist and Nilsson from Sweden presented another computer simulation for studying harvesting machines. The simulation model included two parts, one stand model and one machine model and was a modified model of the work done by Newnham from Canada to suit the Swedish conditions. The stand model consisted of variables identifying and giving a general picture of the stand, as well as variables describing locations and properties of each tree. It did not take into account the terrain conditions which were assumed to be constant. The stands were described by data from field observations and the parameters for machine inputs were: type of stand, number of stand, stand width, stand length, and number of trees. Each tree in the stand is described by: species, DBH, height, length of merchantable timber up to the top diameter 7.5 centimeters, length of log, and volume.

Selected Literature From Other Countries

In Australia, th RW30 Windsor Tree Harvester was tested in a thinning operation in a Pinus radiata stand. Along with productivity and availability statistics, the mechanical and non-mechanical problems of the system were examined:

1. Mechanical Problems- In the felling arm: butt clamp; hydraulic cylinders; and, metal fatigue. In the delimbing function: clogging of the head with cones; branches and needles; failure of the long hydraulic hoses; and, wire rope breakage. In the prime mover: engine overheating; brakes; fire protection; tow hook; and, fuel tank.
2. Non-Mechnical problems- Pressure applied to delimbing knives, knife profile and sharpness, operator visibility, size of main stem, size of and brittleness of branches, angle of branching, wood presented in different form than mills were accustomed to, need of training people employed to work with the system, and versatility (Raymond, 1976).

When evaluating the Logma T310 processor in Pinus radiata thinnings in Australia, the factors mentioned as effective were: soil, slope, thinning type, weather, size of tree, merchantable volume and percent of stem removal. Also, mechanical reliability and utilization of the machine was indicated as well as operator performance. It is worthy to note that night operation was tried and poor lighting was found to be a problem (Raymond, 1979).

The Forest Engineering Research Institute of Canada (FERIC) has published results of a series of studies carried out through their "Evaluation of Logging-Machine prototype" project. The objectives of the project are: "to describe logging machine prototypes and evaluate them with regard to technical characteristics, potential productivity and costs." This project started when the Institute was a part of Pulp And Paper Research Institute of Canada (PARICAN) under the name of Logging Research Division, and has been carried on without interruption since its establishment in April 1975.

Many concepts and prototypes have been studied since then, and factors proven or thought to be effective for any specific system have been considered in the research process. Most reports considered the following:

1. Environmental Factors Included are season, temperature, snow depth, and rain.
2. Stand Description- Details considered are: species composition, volume/acre, volume/tree, DBH, number of merchantable trees/acre, number of unmerchantable

trees/acre, volume of merchantable trees/acre, branchiness, number of trees with branches > 1 inch, number of logs/tree, lean and defect, number of saplings/acre, and merchantability class.

3. Terrain Conditions- Soil, slope, ground roughness, ground bearing capacity, and floatation.

4. General Information- A broad category covering a wide range of information including the name of the developer and manufacturer of the system, technical specifications and ergonomic considerations is recorded. In some studies ergonomic concerns are limited to noise level measurement, but recent publications contain an ergonomic checklist which is a modified version of Skogsarbeten's work.

Many prototype and production machines and attachments, such as skidders, loaders, forwarders, feller-bunchers, processors, and felling shears and saws as well as different yarders and cable systems have been studied throughout the years. In addition, FERIC has attempted where possible to compile long run information to provide the basis for utilization and availability of the systems.

The Canadian Pulp And Paper Association (CPPA, 1975) prepared a checklist for evaluating machine concept and design adequecy. The purpose of this checklist was "to present to designer, builder, and buyer a set of recommendations for logging machines, based upon the collective experience of users, and proposing standards for concept, performance, design, maintainability, and support services." The checklist is divided into sections which contain detailed information on the important parts pertaining to one component or function of the machine. These parts are presented in the form of a questionnaire which asks if the machine has been equipped with them or not. The checklists are categorized as:

1. Logging machine performance.
2. Logging machine design characteristics.
3. Machine safety, lighting, noise, fire and operator comfort.
4. Machine component maintainability and reliability.
5. Logging machine support activities.
6. Contracts and warranties.
7. Value analysis: a recommendation for machine and system evaluations.

The Forest Management Institute, Department of Fisheries and Forestry of the Canadian Forestry Service has been involoved in research and analysis of forest harvesting problems and has contributed significantly in methodological analysis of machines and systems' evaluations and comparisons. One of its major publications is the "Analysis of Tree Harvesting Machines and Systems- A Methodology", a report by McGraw and Silverside (1970). This report presents a methodology which takes into account the effects of tree size and stand volume upon the productivity of the equipment involoved. It allows for meaningful comparison of machine components, machine specifications, different machines and different logging systems. The technique of analysis is a modification of the Swedish Logging Research Foundation (Skogsarbeten) report, "Analysis of Highly Mechanized Logging Systems of Possible Use in 1970", which was modified for application under Canadian conditions.

In this method, machines are described and classified systematically into four classes according to the operations which they perform. For each class, different representative machines are described. A method for analysis of machine performance and examples of how the performance analyses can be applied follows. In order to measure each system's performance, it is necessary to establish average stand characteristics. These characteristics are species, DBH, total height, merchantable height, merchantable volume, number of trees per cunit, volume/acre, distance between trees, terrain conditions, and total area to be harvested. Productivity of each machine or logging system is expressed in volume/productive hour which can then be modified by machine availability, reliability, or efficiency of the whole logging operation to approximate actual operating conditions.

The Forest Management Institute also entered into a contract for the study of the exposure to noise of operators of mechanized equipment in logging operations in Eastern Canada. Under the contract, Reif and Howell (1973) selected sixty-one different logging machines which were most commonly used in the region to be monitored with an "Ear Bug" unit. The study showed that fifty-four percent of machines working in a continuous noise pattern were working within allowable noise limits and forty-four percent classified as working intermittently were found to be working within the noise limits of established criteria.

The Danish Institute of Forest Technology (Skovsteknisk Institute), studied the use of the Stripper II delimbing machine and tractor-mounted radio-controlled winches for thinning. The effective factors mentioned in the report are: species, type of thinning, stand density , residual damage, skid road spacing, age, terrain conditions, slope, soil, DBH, and butt diameter (Clausen, 1977).

The Institute further studied the Danish development of the mechanization of conifer thinnings. Their main concern was to find better machines, better thinning methods, and least cost systems while special attention was paid to silvicultural demands of the stands. For productivity and cost analyses of the systems, time studies were performed and factors considered effective were species, stand DBH, thinning DBH, distance between skid roads, terrain conditions, felling pattern, product form, and volume/hectare (Clausen, 1979).

The Department of Forest Technology of Finnish Forest Research Institute conducts harvesting studies and publishes the results in "Communications Instituti Forestalis Fennica" and "Folia Forestalia". Other private institutions involved in forestry research are the Society of Forestry in Finland with its publications "Acta Forestalia Fennica", "Silva Fennica"; and "Metsateho" which reports its research results in "Metsatehon Tiedotus-Metsateho Report" and "Metsatehon Katsaus-Metsateho Review"; Tyotehoseura, the Work Efficiency Association with its publication "Teho-Periodical"; and finally Oy Keskuslaboratorio-Centrallaboratorium Ab, the Finnish Pulp and Paper Research Institute which acts as an international forum in research. The standardization is maintained by industry.

Metsateho has conducted and published the results of many studies. The format and factors reported in the publications can be summarized as:

1. General- In this section, general information about the machine, how it operates, manufacturer's specifications, how many are produced or annual production, where it was used, price, owner of the machine and detailed technical data on power transmission, wheels, steering, brakes, hydraulic system, and electrical system is presented.
2. Trials and Research Material- Included in this section are date of test, place and site, operator's experience and performance, method of collecting data (time study method), stand, method of cutting, and if applicable, strip road spacing. The time study variables are volume of timber, number of loads, terrain class, distance, and terrain capabilities with regard to ground pressure, slope, roughness, snow, maneuverability and traveling width, and driving speed class. Special attention is paid to injuries of the residual stand caused by machine operation and it is studied by considering the length of strip road, number of injured trees, number trees removed/hectare, volume/hectare removed, number of residual growing stock/hectare, and volume of residual growing stock/hectare.

3. Ergonomics- Maintenance and serviceability is regarded very important and close attention is paid to this matter, especially to those points that need to be checked daily. The evaluation is made by grading each point with very good, good, satisfactory, poor, and very poor. The points checked for evaluation are: hose fittings, emptying of containers, location of air cleaner, location of filters, location of battery, location of fuses, tightening and changing of v-belts, location of electric wiring, location of the oil lines, and location of lubrication nipples. They also include consideration of safety features and evaluate the machines in this respect as well.

The ergonomic and work safety considerations are usually carried out by the Forest Group of Vakola, the Finnish Research Institute of Engineering in Agriculture and Forestry. Vakola, has provided a check-list for ergonomic and safety evaluation of machines. The evaluation is graded with three categories as good, satisfactory, and poor. The check-list includes:

a) Operator's Cab- Length, width, height and seat, access to operator's cab and exit from it, reserve exits, upholstery, color, seat, leg room when the seat is revolving, tightness, heater and its adjustability, cooler and its adjustabiltiy, anti-glare, sideways, backward, driving and working lights, and windscreen wipers.

b) Control Equipment- Steering rods, pedals, pedal actuating force, gear shift, gauges, light and other switches, light signals and acoustic signals, levers, driving and parking brakes, and coding of control equipment.

c) Safety- Fire extinguisher, manual extinguishers, safety switch of the starter, main current switch, location of battery, slipping preventers on the machine walking area. And finally vibration and noise are measured and evaluated.

The Logging Industry Research Association of New Zealand (LIRA), formed and supported by private industry to direct and fund the industry oriented research and development in logging, has been actively involved in machine evaluations. These evaluations have been conducted with regard to the aim of LIRA which is to "improve the efficiency, productivity, and profitability of the logging industry."

The Forest Research Institute of the Production Forestry Division of New Zealand has set up an evaluation methodology for harvesting systems. This methodology is essentially an application of work study, employing elemental time study or work sampling to find productivity and performance of a system. Stand and ground conditions are also assessed, and are carried out before starting the operation. Factors are categorized in the following manner:

1. System Description- A detailed description of the machine and its attachments with basic manufacturer

specification, the layout for the system activity, and method of using the system.

2. Stand Description- Compartment number, species composition and origin, year of plantation, treatment, total stems/hectare, live stems/hectare, dead stems/hectare, volume/hectare, mean volume merchantable trees/hectare, utilizable trees/hectare, residual stems (in thinning)/hectare, mean DBH, mean stem volume, utilizable volume/hectare, stocking/hectare, mean tree height, age, and local volume table.
3. Terrain Conditions- A description of slope, undergrowth, brush density, roughness, soil, and climate detail (weather, rain, and temperature).
4. Ergonomic checklist- All 13 points of Swedish ergonomic checklist have been adopted.
5. General Information- Quality of work done, operator experience assessment, landing condition (if any), and shear damage is considered in this section. Long-term data is a compiled for system availability and utilization calculations.

The Logging Research Foundation (Skogsarbeten), which is supported by both government and private industry and the Royal College of Forestry of Sweden have published the results of many studies conducted in that country. Swedes were the pioneers in applying ergonomic concepts in harvesting machines, and have established many standards for evaluating the ergonomics of a system. These standards, directly or in modified form have been adopted by other countries. Terrain Classification For Swedish Forestry, which classifies terrain into five classes based on three variables (ground condition, ground roughness, and slope), has also been adopted by other organizations.

The ergonomic checklist for transport and materials handling machinery which is in accord with the National Board of Occupational Safety and Health of Sweden, contains the evaluation of thirteen ergonomic principles and recomendations. These considerations are: mounting and alighting, operator accomodation-work position, the operator's seat, the operator's cab, controls, instruments, visibility, lighting, working climate, noise, vibration, exhaust emission, and maintenance.

The stand variables considered effective in machine performance are: merchantable length and bucking lengths, timber weight, tree volume, processing unit (bunch, etc.), winding allowance for correction of crow fly distance (roads), merchantable length in meter/tree, geometric mean between maximum merchantable length and 15-meters.

merchantable length, growing stock/hectare, percentage of trees to be logged, distance (crow fly distance), machine performance in centiminutes/tree, speed in meters/centiminute, and felling area per processing site.

Whayman (1968) in England studied the possibility of using a small articulated tractor for extracting thinnings. The Holder A20 was used and the recorded factors were: trail spacing and their layout, slope, directional felling, volume/bunch, height of stumps, drains' depths and safety of cab.

Warkotsch (1982) from South Africa, proposed another evaluation method based on an approach which analyzed the harvesting systems in a comprehensive and compatible manner. The procedure is that before any comparison is made, the technical suitability of the system must be checked. All the influencing factors and relevant criteria must be considered. These criteria include: economic; labor-economic; social organization; ergonomic; silviculture; and, ecology. The method recommended for evaluation with regard to these criteria is a compromise between cost-benefit and monetary evaluation methods. First, the alternatives are compared on the basis of economics and labor as the most important criteria. If the results do not satisfy these criteria, no further investigation is needed and system use is ruled out. But if satisfactory results are obtained, the second step is to investigate other influencing factors and if there are several alternatives, qualified for consideration, then comparison will proceed based on a cost-benefit analysis. The important characteristics which determine the applicability of the system are regarded to be tree species, stand density, average tree removed, DBH range, average tree volume, saleable volume per tree, cutting type, product type and form, terrain classification, road spacing, transport distance, slope, quality, and labor performance.

Summary

From the foregoing review some conclusions which form the basis for this research project can be drawn:

1. There are similar formats and procedures to deal with the problem of collecting data and effective factors for analysis among studies conducted. These similarities and considerations are more common among established organizations. Through time, this commonality is more visible mainly because of increased and better communication as well as adoptation.

2. Even with all of the indications of similarity, the lack of a common measuring system, and a standard format is a common problem. At this point it is clear that there is no comprehensive method of recording and reporting which provides a unified method across national borders.
3. Even though attention has been paid to human factors in forest harvesting and more ergonomic concepts are being adopted into system evaluation, at this point there is no international standard. An important factor missing in ergonomic evaluations is machine maintainability design which has proven to be one of the most important elements of utililzation and mechanical availabilty.
4. One of the basic rules of the validity of scientific investigations is the ability to duplicate a study if required or needed. Although the nature of harvesting does not permit it, and there is no way to physically reconstruct the forest after logging has taken place, the rapid expansion of computer use provides a unique opportunity for recreating the stand and logging it again and again. There is no doubt that better and more accurate results of simulation can be achieved by better and more accurate input. Thererfore,

capturing more details and important factors thought to be effective in the harvesting process, will bring the simulation closer to "reality".

5. Throughout the review, it was observed that different methods of collecting data as well as procedures to analyze them have been employed. It was also noted that in some cases the same system was used in different locations by other investigators, but they did not consider the same factors.
6. Even though time study was the dominant method of collecting data for machine performance, other methods like work sampling and total time spent on work during the day was used as well. The analysis of time data collected by any one method, ranged from simple average time per activity to multiple regression. In many of the studies, analytical results were the basis for the development of production and cost equations. Most cases had time study results tabulated and equations were given, but in some cases the time averages were the end result reported. Very few studies had compiled enough data to provide documentation of utilization and availability.

METHODS AND PROCEDURES

The development of the standard set of the forms for international use was accomplished in three stages: Classification of Influential Factors; Drafting of the Format; and Guidelines Instructions.

Classification of the Influential Factors

During the review, the factors and elements considered and recorded for each study were examined and categorized based on the type of information they contained. This cross examination provided a good insight on how diverse the recording and reporting methods were and what factors or parts were neglected or failed to be reported. This was true especially with regard to human factors and maintainability of the systems which were not considered at all or were not comprehensive. There were many publications dealing with the various segments of system evaluation and man-machine relationships. It was recognized that a great number of these concepts could be used, and incorporated into this research.

Drafting of the Format

The format was prepared following the APA-HRP (1971) layout and was structured as closely as possible to the Oxford System of Decimal Classification for Forestry (1954). The structure was based upon the intensity and duration of data collection. Three levels were considered:

1. Level One- A general daily collection of data concerning equipment, productivity, labor, and the environment to provide basic information for system performance.
2. Level Two- More detailed information about the operation. At this level different design and sampling methods for statistical analysis like work sampling studies, cycle level studies, service recorder studies, spot stand checks and spot soils/terrain checks are considered. These are performed on a sampling basis over the duration of the study period.
3. Level Three- Highly detailed, intensive studies which are conducted infrequently. These studies include elemental times, ergonomics, volume tables, soil bearing capacities, and fuel consumption.

In drafting the format the following categories were considered: Environment Description; System Description;

Performance Measurements; and Machinery. Each one of these broad sections were further broken down into specific sub-categories which will be discussed and rationalized in subsequent sections.

Guidelines and Instructions

This portion of the research dealt with defining the collection methodology and procedures which are combined with the developed forms, to serve as a field manual. Each term and procedure required is clearly defined in order to avoid any ambiguity or conceptual mistake. It also describes the tools and equipment needed and procedures to follow in order to collect the required data. The field manual is out for critical review. It will be published separately and is not a part of this dissertation.

FORMAT LOGIC

The rationale for the development of the format and structure of the field forms for international use was based on factors affecting machine and system performance, machine design characteristics, and analytical techniques. The logic is discussed in four major categories. Following the Oxford Decimal Classification for Forestry Systems, the structure of the format is maintained as 306.10 for Environmental Factors (or Factors Affecting Work), 312 for System Description, 352 for Performance Measurement, and 370 for Machinery and Human Factors.

In each category, different factors have been considered and each factor may have one or more elements in it. These factors and elements are those that have proven to be effective in one or more parts of the logging process, even though not all of the effects have been yet quantified. Every attempt has been made to make the forms understandable and easy to fill out while collecting detailed information. In most cases, only a check mark in the appropriate position is required. However, there is no need to fill out all forms. All or part of the forms or even some selected sections of a form may be used to satisfy the needs of a particular study. The choice of selecting the required forms depends on the user, the nature of the study, and the applicability to the system under study.

Not all sections are devoted to effective factors. Some are related to the characteristics or design of the system and some to analytical data collection which all together make it possible to have the basis for a more realistic assessment of the system. All units are presented in Metric System.

The developed forms are presented in the appendix. Some of the forms were used in the field tests and are examples of their application.

Environmental Description (306.10)

This broad section encompasses different factors critical to logging productivity and costs. Their effects range from little or none to stopping the entire operation.

This section has been divided into the five subsections of: weather conditions (306.101); ground conditions (306.20); working conditions (306.30); stand type, stand conditions (306.40); and harvest strategy and history (306.50). It should be noted however, that some factors may be considered in several places because they infuence different activities of the logging process. As an example, slope is considered in felling, skidding or yarding, landing, and hauling because of its effect on all of these processes.

Weather Conditions (306.101)

Variables considered in this part are temperature, wind, humidity, precipitation, and atmospheric conditions. Weather conditions may interfere with logging operations and the efficiency of men and machines, particularly when weather conditions are at extereme situations. The impact of weather varies from lowering productivity to complete stoppage of operation. Each one of these variables has its own impact and sometimes their combined effect is drastic. Since weather variables may change rapidly, all measurements should be recorded daily. Most of the weather information can be obtained from a local weather station or a local radio station.

1. Temperature- Machines may have starting difficulties when the temperature is below zero. Engines may overheat when temperature is high. People have difficulty carrying out tasks under extreme temperatures, and ground and stand conditions are

influenced as well. A thermometer on site may be used to record the temperature.

2. Wind- Wind has an effect on the cutting and especially the direction of fall for felled trees as well as the outbreak and spread of fires. An on site anemometer (wind gauge) can be used or an estimate can be made using a Beaufort scale. Wind direction can be indicated by bearing or azimuth. If the wind direction and speed is the same for more than 50% of the time, it is considered as constant. But, if it blows less than 50% of the time with a speed which can be recognized only at peak velocities, it is occasional. An irregular wind changes direction or velocity more than 50% of the time.

3. Humidity- Humidity, especially combined with high temperature strongly impacts on the human body and the efficiency of people may drop significantly. Most local radio stations include humidity levels in their weather reports.

4. Precipitation- Precipitation of any type has a great impact on logging operations particularly on in-woods transportation. The result of precipitation may vary based on locations and situations. For example, the impact of snow varies with the terrain. If the

working area is steep, just a few millimeters of snow makes the work situation hazardous. In other areas, as snow depth increases, harvesting can still be done, but with lower productivity.

In addition to the type of precipitation, the duration and intensity are also important. Duration is important not only because of the amount of precipitation, but also because of its distribution throughout the shift. One hour of continuous rain has greater impact than one hour of rain spread over an eight hour shift. Also it is quite possible that the precipitation type might change within a few hours or during the day. Therefore, along with the type of precipitation, its duration and accumulation should be recorded at least to the nearest quarter of an hour. The measurements can be taken from a simple rain gauge.

5. Atmospheric Conditions- Atmospheric conditions should be recorded because sunshine or fog or overcast, has an effect on body tolerance to temperature, humidity, and visibility. Less than 50% cloud cover is indicated as clear, greater than 50% of high clouds is cloudy, and if low lying clouds are present then it is overcast. Sufficient atmospheric moisture

resulting in decreased visibility is considered a foggy situation.

Within the same area, skidding or forwarding is carried out on many different traces. These changes, require daily recording of the average skidding or forwarding distances. This is the reason why this factor was added to the section on weather conditions. Usually, the skidding or forwarding distances are recorded in Kilometers, therefore, an estimate to the nearest 50 meters will be adequate. Form 1 (page 151) in Appendix A is used for recording weather information and skidding, forwarding, and yarding distances.

Ground Conditions-General (306.20)

Slope, soil strength, roughness, depth of humus layer, slope direction to the access road, soil moisture, and snow are variables considered in the recording of general ground conditions. They are influential in logging planning, operations control, and must be considered in machine evaluations or comparisons as well as in the system development stages. Ground strength, roughness, and slope classification have been based upon the Swedish and Canadian classification of the ground conditions. Skogsarbeten (1969) published a report on Swedish ground classification. This was modified for Canadn applicationon (CPPA; 1980). These classifications have five classes for each. These should be recorded at the beginning of the study and anytime that the conditions change or the operation moves to a new site.

1. Slope- Slope is especially important on skid trail and road location as well as the logging systems employed.

   Steep terrain makes movement and felling much more difficult and dangerous. The productivity of a felling crew on a favorable terrain is much higher than on unfavorable terrain. For the cutting phase, perhaps the most significant variable is terrain. Development of shears and feller-bunchers, and in general, advanced harvesting systems, raises the question of suitability of the machines to the area and slope is usually the first and most basic consideration. Steep terrain prohibits the use of certain machines and in some cases forces the use of other machines with specific features.

   If mechanized cutting systems are precluded then power saws have to be used. The use of chain saws will bring about other considerations. Again the very first thing to look for is slope, because steep slopes increase timber breakage. Holding the cut trees on hill sides is very difficult and sometimes impossible. This is especially true with larger trees on steeper terrain. On steep slopes, because the cut trees roll, bucking (if needed) takes more time because of travel time from stump to the runaway tree.

Topography and soil are the most important factors influencing road construction, maintenance costs and logging methods. Constructing roads on steep slopes means deep side cuts and greater erosion problems as well as more switchbacks which reduce hauling speeds and increase brake wear. On some flat ground, with fine silt and clay sub-soils, there is a problem with water capillarity and soil stabilization is required. This increases construction costs and adds to skidding and hauling costs. On steep slopes, finding flat places for landings is difficult and landing preparation and maintenance is more expensive. It is clear that on steep terrain the road distances for hauling will increase, resulting in longer travel time and fewer loads per day. Slope measurements are recorded as the average readings in the direction of maximum slope over horizontal distances of at least 25 meters. A number of measuring points are distributed over the area. But, if a specific direction is intended as for skidding, the slope of that direction in percent should be recorded.

2. Ground strength- It is essential that the ground has sufficient strength to support the foot pressure of loggers and has the capability of bearing machines with minimum sinkage. Contact pressure is the weight per unit area; therefore, the pressure that a person or a machine exerts to the ground can be found by dividing their respective weights by the contact area.

   The Canadian Pulp and Paper Association (CPPA) has derived five categories of ground strength based on weight per unit area for men and machines and how they can be measured.

3. Ground roughness- Rough terrain with obstacles makes man and machine movement difficult. Terrain roughness also impacts on felling and bucking, skidding, landings and road construction. On rough ground, there is an increase in timber breakage and bucking is more difficult and more dangerous. The cost of preparing landings and roads in rough terrain will be much higher. Capacity for traction/floatation differs with the soil type, moisture content, and structure. This capacity is good for friction soils and bad for

cohesion soils when wet. The better the traction, the faster the skidding and thus the lower the cost. Tire penetration will increase rolling resistance which will increase as skidders negotiate wet, muddy ground and results in less usable pulling force.

4. Depth of humus layer- The depth of the humus layer influences the movement of man or machine, and impacts the felling process. A thick humus layer is a good cushion for falling trees and preventing breakage. It also holds moisture for much longer periods of time. In order to determine its depth, several measurements should be made over the site and averaged. A soil auger, a shovel, or probe can be used to measure the depth which is from the top of the duff to the surface of the mineral soil. Unusually thick or thin spots should be avoided.
5. Slope relation to access road- Whether the grade to the landing is favorable or adverse when the machine is loaded is important. If this direction is uphill (adverse) it takes more time than a downhill or level trace.
6. Soil moisture- Soil moisture is the final factor which should be considered in describing ground conditions. Some soils are dusty when dry but as soon

as they get wet, become slippery. Soil moisture has potential to create additional problems as was stated before. Wet conditions on landings and roads can cause problems in loading and hauling plus making logs muddy.

A general assessment of all of these factors should be considered independently, then an overall judgement on traficability of the ground can be made. Form 2 (page 152) is developed for recording data on ground conditions.

Working Conditions (306.30)

This subsection considers conditions of the stump area (306.31), stump processing (306.32), stump area transport (306.33), strip road/skid trail (306.34), landing or road side (306.35), hauling (306.36), and terminal (306.37). The recording can be done whenever new conditions are encountered and need not to be done everyday.

The variables considered are slope, footing, soil moisture, ground roughness, brush density, residual (slash) and residual stand, walking quotient, material organization, origin of skid road, surface composition, skid road alignment, hauling distance, road class, road ownership, and terminal type and capacity. Some of these variables impact on several phases of the harvesting process, and some are related to just one phase of it.

1. Footing- Soil and ground conditions have great impact on chain saw operator movement. If the footing is firm, there will be no sinkage or slipping in walking, therefore, faster movement and less time to perform the job. But slippery, muddy, or loose ground makes it difficult to move around and slows down the performance. When conducting time study or any kind of data collection, the footing conditions should be observed and take into account.
2. Brush density- productivity, safety of felling, and skidding operations are influenced by brush density. In felling, a good deal of time is spent walking from one tree to another. Preparing the skid trails will be more difficult and take more time. In small timber the impact of brush is higher than that of large timber especially with regard to bucking. Safety considerations come into play in felling which requires cleaning around the tree and cutting an escape path. Even though mechanized cutting is not influenced by brush density as much as motor-manual methods, it will result in reduced production.
3. Residual (slash) and residual stands- Slash causes additional problems. These residuals are in the form of stumps and branches broken or cut after topping

and bucking. The stumps interfere mostly with skidding and the slash interferes both with walking and skidding.

It is important to know the type of cut that is to be made, and the character of the residual stand, if any. The residual stand is measured by the percentage of the trees over 10 centimeters DBH that are left standing after felling activities are complete. If the residual trees are cull trees, then there is no concern for them during harvesting. But if the operation is meant for timber stand improvement, then care should be taken to keep damage to a minimum. The care required to harvest with acceptable damage to the residual stand in partial cutting will be reflected in higher costs. In most cases however, moderate damage is acceptable for pre-logging operations.

4. Walking quotient- The effect of forest conditions which impede the motion of man and machines may include slope, brush, residual trees, slash, snow, or any combination of these factors, and can be indicated by calculating a walking or machine movement quotient. This quotient is the ratio of the time it takes to walk a certain distance in the

woods, compared to the time it takes to walk the same distance on a road or open trail. This ratio shows how hard it is to move or walk in the woods, and provides a quantitative measure of working area conditions. Larger ratios indicate worse conditions. The walking time in the woods should be measured several times in different directions and the average time used for comparison with the time obtained on the open level space or road. But if a certain direction is of concern, the course should be paced several times to arrive at an average.

5. <u>Material organization</u>- The pattern of felling trees must be checked and recorded as it is practiced. This affects both the felling and subsequent processes. If directional felling is conducted, the cost of felling will increase. But the cost of processing will be lower and the operation will be easier. On the other hand, random felling will make the felling faster, but no orientation of the trees will cause problems in following activities. This is also true for bunching and piling which may take much more time and effort but the following processes are easier and faster.

6. Origin of skid road- The origin of the skid road, refers to the amount of work spent on its preparation. The more work and effort made, the better the road will be. If the road is made only by machine movement while skidding, it is referred to as a "no preparation skid road." The other extreme, is when one is well prepared and surface materials have been applied. This skid road is referred to as "bladed, ditched, and some surface applied." Depending on the situation and the type of work done on the skid road, the cost will differ and must be taken into consideration.
7. Surface composition- Surface composition refers to the material in the top 10 centimeters of the trail. The type of the material present will have a significant effect on travel speed. Surface composition is important by itself, and its impact is magnified by precipitation.
8. Alignment- Straight alignment is the best and least time consuming for travel. Straight alignment is defined as one which has one horizontal curve or less per kilometer, with a radius which is greater than 75 meters and a length equal to or less than one-half of curve radius. Slightly curved alignment is one with 2

to 3 or less curves per kilometer, the curve radii greater than 50 meters, the length of curves equal to or less than curve radii, and no compound curves. Winding alignment is one with 4 to 6 curves per kilometer, curve radii greater than 25 meters, length of curves 1.5 x curve radii or less, and 1/3 or less of the curves are compound. Crooked alignment is one with majority of the curves compound, the curve radii greater than 15 meters, length of curves 2 x curve radii or less, and 9 or less curves per kilometer. Very crooked alignment refers to unlimited curves per kilometer many of them doubly compound, the curve radius less than 15 meters, and the length of curves greater than 2 x curve radius.

9. Hauling distance- When considering hauling characteristics, it is first necessary to know the haul distance and the market to which the product will be delivered. All products may not go to the same end point, therefore the haul distance for each product may differ. Thus, careful sorting of logs should be done at the landing for loading. Various destinations will cause the hauling time to be non-uniform and receiving facilities at each delivery point will add to these differences.

10. Hauling road class- The class of the roads travelled and their related conditions will materially affect hauling time. High quality roads with enough width and wide curves, facilitate better speeds than poor roads with minimum width and sharp curves. If hauling is done by a separate contractor, then steeper and rougher roads may be subject to higher rate. The conditions of any class of road may still cause differences in travel speed. Mud or snow makes roads slippery and results in slower speeds. Fog or dust may result in poor visibility, slower speeds, and increase the probability of accidents.

11. Road ownership- Depending on the ownership of the road, private or public, regulations and permission for limited use and standards will vary. In many areas, private roads offer distinct hauling advantages such as no weight or size restrictions, no licencing and no use taxes. Because there are weight, width,and length restrictions on public highways, small payloads are usually hauled. The higher quality of most public roads allows higher hauling speeds and less wear and tear on equipment.

Private road classes can be defined and characterized as:

Temporary roads: no ditches, vertical cut banks, 4 meters width or less, turnouts 0.5 kilometer or more apart, 16% favorable grade, 12% adverse grade, curve radius 15 meters or less, may be temporary or reserved for occasional use.

Permanent- Class 3: ditched with water bars and culverts, cut banks and fills appropriately sloped for local soils, 4 meters width with 7 meters width at turnouts, 10% sustained favorable grade- short distances of up to 16%, 8% sustained adverse grade- short distances of up to 12%, curve radius 15 meters or more, surfacing only in weak spots, occasional maintenance.

Permanent- Class 2: ditched with culverts, cut banks and fills graded and seeded, 5 meters width with turnouts, maximum sustained adverse and favorable grade- 10%, for distances of 150 meters 12% favorable, maximum curve 55 degree with 30 meters radius, switchbacks 15 meters radius, regular maintenance (grading, cleaning ditches), and surfacing where needed.

Permanent- Class 1: same as class 2 except that 9-10 meters width to support 2 way traffic over entire length, surfacing material applied over entire length, routine maintenance allows speeds in excess of 75 kilometer/hour.

Public road classes can be defined and characterized as:
Public- Class 5: same as private class 3 except the regular maintenance and culverting more common, single lane bridges.

Public- Class 4: same as private class 2 except for regular maintenance, surfacing in areas of heavier use and weak spots.

Public- Class 3: same as private class 1, surfacing may be bitumious or gravel, may have center line and indicated passing zones.

Public- Class 2: bituminous or concrete surface, width in excess of 10 meters, shoulders well maintained, center line and edge lines present, warning signs where needed, and supports 2 way traffic at posted speeds.

Public- Class 1: divided highway, 2 or more lanes moving each direction, may be limited access.

Urban roads: village or city streets, speed controlled by posted limits and affected by traffic.

12. Terminal (or delivery point) type and capacity- Based on their type and management as well as their capacity and storage period policy, terminals have different impacts on the previous phases of harvesting. The terminal may be a one-week or two-week storage end-point, it may be small or big, it may be near a highway or bayside, it may be used just as a waiting place for further transportation, it may be a sawmill or veneer plant ready to accept logs for lumber production or veneer and/or plywood, it may be a pulpmill to recieve roundwood or chips to produce a market pulp or paper, or it may be an energy concern that recieves residues, chips or roundwood for producing heat. Any one of these conditions has a different effect on the hauling process and logging management has to take into account the impacts accordingly.

There are different scaling methods which may be used by different terminal type:

-Piece scaling, indicates each individual piece is scaled.

-Load scaling, is one that the delivered volume is determined by taking gross measurements of length, width, and height of the load and applying the appropriate conversions.

-Weight scaling, indicates that the truck and load are weighed at the time of delivery and the empty truck is weighed as it leaves the yard.

Another point regarding the terminals is the unloading method which has influence on the total hauling time. Unloading may be done manually, self unloading by means of a crane mounted on the truck, by cable or hydraulic crane provided by the yard, by machine unloading, or dumping.

The basic question with respect to terminals may be to ask how much wood and how many types of logs will they accept at what delivery rate.

In short, effective management should be aware of these processes and their impacts and act accordingly. Forms 3 through 10 (pages 153-162) are used to record the information related to the foregoing discussion

Stand, Stand Condition (306.40)

Today, with residual harvesting and wood energy in the picture the value of each part of tree up to the smallest branch, even cull, down, and dead trees, must be considered as a potential product.

The decision of how much of the tree and what parts are to be harvested, impacts the selection of machines for felling, skidding, processing, loading, and hauling. Adding a machine or single function to the existing system will have a chain reaction and must be considered carefully to maximize the efficieny of the operation.

With regard to the stand, the characteristics to be considered are volume, density, height, origin, history, and management activities.

1. Stand volume- This variable determines whether it is worthwhile to take any action or not. If the volume is low, it may not pay the costs of moving equipment nor the costs of landing and road construction regardless of what type of logging system is used. Low volume per hectare requires more work for each unit of volume produced. High volume brings down fixed costs per unit volume of production.

   Volume to be harvested is dependent on the type of cut as well as the location of the stand. A high volume in a thinning operation is different than a high volume in a clear cut and both cases will be different whether they are in northern Europe or the western North America.

Within the same volume per hectare, there are other factors with relatively significant influence. Is the timber hardwood or softwood and of what species? Limbiness causes problems in felling and skidding. In addition, limbiness impacts processing in the mill as well. The market and price will dictate whether to cut a tree of certain species or not. Still another factor within the same category is whether the volume referred to is merchantable volume or not. The required information consists of total volume per hectare on the tract which is to be used by the operating company and the break down of merchantable and unmerchantable volume as well as indicating whether the total biomass above ground or above and below ground is used. A breakdown of hard and softwood volumes as well as related species must also be specified.

2. <u>Stand density</u>- Stand density is a quantitative term and describes the degree of stem crowding within a stocked area and usually is expressed by basal area

(BA) per hectare. It may also be expressed as the number of trees per hectare which is extensively used in planted stands (Avery and Burkhart, 1983). With regard to harvesting, stand density provides information about size and number of trees per hectare. If tree size is small, then a greater number of trees must be cut in order to get the same output. The felling and especially moving time from one tree to another is almost the same whether the tree is small or large. This is also true for cable skidding and yarding where it takes more time to move around and set chokers on more logs, to make a load. Stem size also has a definite impact on mechanized harvesting with regard to feller-bunchers which until now, were not capable of performing on ground line diameters over 50 cm. Stem size has an impact on all system components. The time required to load a truck, whatever equipment is being used depends on log size. The lower diameter limit which is set by the company should be recorded.

3. Stand height- Another factor which directly influences the volume, is the height of the tree. Also, the height of saplings is important for felling considerations. Preventive measures should be taken to keep damage to trees or saplings at a minimum.

4. Origin of stand- The origin of the stand whether natural, seeded, coppice, or grown under some special silvicultural treatments, impacts the stand, size, and spacing between trees. These in turn influence logging decisions and output expectations.
5. Stand history- Another piece of information which is useful in planning is stand history. That is, what management activities have been carried out and at what time. Any catastrophe has an impact on the stand, and the measure of its result is related to its severity. In any event, the result of the catastrophe affects quality as well as quantity, and is based on how much damage was done to the stand.
6. Management activities- Previous management activities such as sanitation cuts, precommercial and commercial thinning, selection harvests, prescribed burns, and chemical release have great impact on the present condition and quality of timber stand. All of this information is required for proper logging planning, and for the marketing of timber.

Obviously, the form required for this part is recorded before any operation takes place, and at any time when changes are sufficiently significant to warrant a new description. In order to understand and communicate properly, the units used in cubic meters, must be specified in terms of solid wood, wood and bark, stacked volume, tonnes or any other forms of measurement. Form 11 (page 163) will be used to record all this information.

Check Plots (306.42)

Because of differences in stand variables, it is very rare if not impossible, to find two timber stands (even an area as small as a hectare) that are identical in all silvicultral characteristics. A constant check on stand conditions is needed to see if changes are sufficient to call for a new description. This check should be conducted at least once a week by taking check plots which contain at least 7-10 trees. The plot should be selected randomly and any accepted sampling method (random or mechanical sampling) could be used. Plots should be installed in a portion of the stand that will not be harvested for several days. This will give sufficient time to set the plot, record the tree characteristics, and check to see if there is significant difference in stand conditions. If there is enough difference to warrant a new description, then proper action can be taken. All features of the stand especially species, tree size, density and other characteristics of the timber which affect the production of the harvesting system should be recorded in each plot. Form 12 (page 164) is used to record the collected data.

Volume Table Development (306.43)

The average contents or weights of various sizes and species of the standing trees can be estimated by using volume tables or equations. These relationships use diameter at breast height (DBH), tree height (total or merchantable), and, perhaps, tree form as the principle variables of tree volume. Local volume or single-entery tables are based on the single variable of DBH and may be constructed from existing multiple-entry volume tables or from the scaled measure of felled trees (Avery and Burkhart, 1983). To check the accuracy of a regional volume table, a local volume table should be developed at least once per study. The local volume table assumes all variables, except DBH, are uniform within the limited area for which the table is developed. This means that trees of a given diameter class tend to be of similar height and form. If consistant significant differences between local and regional tables are observed, then it may be necessary to increase the activity of developing local volume tables in order to construct a more reliable local table. This will simplify data collection since only DBH is needed to obtain system output. Forms 13, 14, and 15 (pages 166-168) were developed for the data collection required for volume table construction.

To construct the local volume table, the trees representative of the stand should be selected. For a homogeneous stand, one sample will be enough but, for heterogeneous stands (different age classes, species, or from diverse sites), a sample may be required for each sub-group. Three separate forms based on three different height categories (10 meters or less, 11-20 meters, and 21-30 meters) are suggested. The first category constitutes the trees of small diameter which if harvested, may be used basically for uses such as poles, pulpwood, or energy source. The second category, in addition to those products obtained from first category may provide more valuable timber such as logs for lumber. The third category may produce additional valuable products such as veneer and plywoods.

Measurements taken at suggested interval for each category will provide height measurement at any level needed up to total height and if needed, it can be used for taper form measurements. Most importantly, it provides information about total volume or weight loaded or skidded by a harvesting machine. These measurements are important because trees may be cut and be left whole trees, may be topped to merchantable height, or may be bucked into several segments. Smaller trees may be bunched to make a full load for larger and more powerful machines. In any event, the carrying capacity of the machine and the market requirements dictate the appropriate decision. For production and cost analysis, the total volume or weight handled by the machine should be known and these tables can be of great help.

To provide weight tables, each bole or full tree length can be lifted at or near the center of gravity and weighed by means of a dynamometer.

Forest Model (306.440)

For detailed descriptions of harvesting conditions, which basically are required for intensive time study of the operation, Forest Models should be established on the study area. The second edition of the Forest Model Manual of the APA-Harvesting Research Project (1969) and the revised and modified instructions prepared for this research can be used, which explains in detail the layout and procedures of collecting data. Form 16 (page 169) is is used to record the information from the Forest Model.

Residual Stand Damage (306.451)

After the operation is completed and machines have been removed from the Forest Model area, an assessment of damage to the residual stand, soil, or other important features is recommended. The survey is divided into two parts, one for timber damage and the other for soils and site damage assessment. The Forest Model is visited again after harvesting and the tree number of any tree left standing with over 50% estimated chance of survival should be recorded. The left tree may have been a missed harvest tree, a leave tree as future crop, an unmerchantable large size tree left because of a lack of markets, or a small tree left because of the size. All these should be indicated as such when recording. The damage to the tree must be indicated by its type and extent, and may be a broken top, limbs broken off, and bark knocked off.

To record the soils and site damage, a rough sketch map of the area should be included with roads, streams, barriers, or any related information. Areas subject to damage can be pointed out by a letter code. A legend at the bottom of the map will serve to describe the to describe the codes. Forms 17 and 18 (pages 170-171) are are used to record timber and soils damage.

Harvesting Strategy and History (306.50)

Harvesting Strategy (306.51). The strategy of harvesting, with estimates of amount and type of material and the sequence of processing is important. Included in harvesting strategy is a map of the tract layout with its geographical location, major stand types, landing and roads, major obstacles such as streams and rock outcrops or marshes, skidding trails, and the north sign to show the direction. A list of follow up activities from the contractor or the organization responsible for harvesting should be indicated. This information is important, not only to know the situation in the area but, because it has great impact on planning both for the cutting, skidding processes, and other activities related to the process.

The sequence of harvest can be described by reference to the proper location of starting the cut and the direction to be followed and an indication of the type of cut. The major functions such as cutting, skidding, loading with their estimated time scheduled can be listed in order of occurrence. On site inventories are an average estimate of volume or weight contained in each process area. Any special condition noted during the process like working on very rough terrain or in a swampy area should be recorded. Form 19 (page 172) is used to record this information.

Harvesting History (306.52).

A history of harvesting activities regarding the related amounts and dates of acomplishment prior to the initiation of the study will be informative and effective for planning and harvesting strategy. This history should include such information as access roads and landings installed previously; the length of operation in process prior to study; volume harvested to that day with a breakdown of volume removed from the site or being processed; efforts related to preparatory activities like boundary marking, and marking corridors. The approximate date of the last previous harvest on the area should be indicated. Form 20 (page 174) is used for harvesting history information.

System Description (312)

The type of individual, his or her character, ability, experience, and interests play major roles in all aspects of harvesting. The type of crew or organization to which these individuals belong, how the organization works and what kind of business or experience it has, or what kind or part of harvesting is involved, also has great impact on the whole process.

Factors considered are business type, crew type, supervision, protective clothing and personal equipment, first aid and safety training, employee description, task and skills, periodic pay and production, accident and illness, resignation/termination, system description, system longevity, system ownership, production history, operation history, and average crew size.

1. Business type- The ownership and organization of the operation, whether it is a company or a private business, is important. If privately owned, the business may be a sole proprietorship, partnership or a corporation. If the harvesting system is divided among several contractors which have conflicts or need to make decisions through other channels, then the whole process will be different.

2. Crew type- There are differences in efficiency as well as proficiency between an established production crew and a newly formed or experimental crew. The supervision of the operation makes yet another difference.

3. Supervision- If the owner acts as a superwisor and/or a mechanic or these jobs are done by others, it will make a difference not only in work performance but also in equipment maintenance as well as in the human relationships between the employee and employer.

4. Protective clothing and personal equipment- These are needed for a safer harvesting operation and can be provided by the owner or purchased by the crew member. Proper clothing is required to protect the person from dangers in woods operations as well as extreme environmental conditions.
5. First aid and emergency medical care- Accidents often happen despite all safety measures taken by the crew. Because of the situation of the harvesting areas which are usually far away from medical centers, first aid and emergency medical equipment are a must. They should be carried by each crew or in each machine to provide first aid.
6. Safety training/enforcement- Providing the emergency medical care and safety equipment is not enough. The people, at least one in each group should be trained and know how to perform emergency care. In addition, all crew members should be familiar with safety rules.

The safety of the crew, protection measures, first aid, medical care and safety training are considered very effective. This is not only for humanitarian purposes and compliance with the law, but it is in the best interest of the organization. If safety is neglected and an accident occurs, the expense related to loss of people, equipment, time, and interruption of the operation far exceeds the cost of providing these benefits.

7. Employee description- In order to evaluate a worker, it is necessary to have enough information about the person (including age, harvesting experience, time with the crew) as well as the wage or salary system, and his or her tasks and skills.
8. Tasks and skills- Each employee's skill level in their assigned primary, secondary, and tertiary tasks should be recorded. This information can be used to assess the potential of improving production.
9. Periodic pay and production- In order to keep track of labor performance and the related measures between methods of payments and output, it is required to record the periodic pay and production at the end of each period for each person.
10. Accident and illness- A record of illness and accident will provide current information on the employee's health and, if applicable, the cause of accident and corrective actions performed.
11. Resignation/termination- A record of resignation or termination with the related reasons will provide

information on job allocation, and the availability of the labor for certain seasons of the year.

12. <u>System description</u>- A major part of the system is machinery. The types of machines used in the system are important. An established production system has different output and performance than an experimental operation.

13. <u>System longevity</u>- It is important to know the years or fraction of a year that the system has been in service. The longer the system has been in operation, the more established it is. Characteristics and abilities of the system are known and it is possible to have better programming in order to take full advantage of the system services.

14. <u>System ownership</u>- The type of ownership has great effect on planning, management, maintenance and utilization of the system. It should be known whether the system under investigation is a part of a firm or a government or a research project. The condition and especially the full operation of the system will differ from one agency to another.

15. <u>Production history</u>- Because of the many variables involved in the harvesting operation and significant differences among variables, the output of a system

fluctuates daily. Therefore, a long run recording of daily and weekly production is needed to obtain a reasonable average productivity of the system.

16. Operating history- Operating history will provide a good insight to system performance and productive hours worked. An accurate, intensive time and cycle study of a system will provide a very precise model for system performance. However, it never reflects the downtime related to maintenance and repairs or other problems.

17. Average crew size- Maintaining a constant crew size is difficult. In specific situations, the crew size may be adjusted based on timber volume and available machines as well as the difficulty of finding labor. Even if the rate of turnover is high, an average crew size may be estimated for further investigations, analyses, and productivity estimates.

These details related to foregoing dicussion, are recorded on forms 21-26 (pages 175-181).

System Description (312.20)

A major part of the system is machinery. Each type of machine has its own impact. It is important to know the years that system has been in service, its ownership and the crew size working with the system can be important. The production and operation history will provide a good insight of system performance and productive hours worked. It should be noted that an established production system has different output and performance than an experimental operation and this difference must be considered in a production study. Form 28 (page 182) can be used for recording the system description.

Material Flow (312.21)

Material flow can be described with regard to the sequence of activities, function descriptions, and work units. Starting with standing trees, there are events and actions that take place which change the form of the tree such as felling, limbing, topping, bucking, skidding, forwarding, or yarding. At any time that a change in the sequence occurs, a new recording should be made. Understanding the flow of activities provides background for control and planning. It is easier and faster to indicate the sequence of an operation using a prepared flow chart with standard symbols than attempting to describe with words.

The delivered product may be whole trees, tree lengths, shortwood, or shortwood piled roadside. For each product form, different processes will take place and have their own functions. Therefore, by declaring the product form, corresponding functions should be indicated. Form 28 (page 183) is for material flow recording.

Machine Conditions and Dimensions(312.22)

Along with material flow, machine task descriptions as well as machine conditions and dimensions should be stated. It is very important that the machine operator knows which task he or she is assigned to, and all subsequet activities. If a machine is ready to work but no task is assigned, it would stay idle. Not only the productive time is lost, but it also affects other operational activities.

Each machine should be identified and all information including make and model, dimensions, price, and its condition by indicating whether it is excellent, very good, good, fair, or poor should be recorded. A machine in excellent condition should have high mechanical availability and be quite productive. But under the same circumstances, with the same machine in poor condition, the productive time will most likely be low, because of the many mechanical and maintenance problems encountered.

This information provides a good basis for cost analysis and productivity comparisons. Machines should be described as a first or second prototype, preproduction machine, or production machine. This is necessary because from the first prototype to the production stage, there are many changes and modifications which affect the output production. Machine activity can be described using flow charts as in material flow. Forms 29 and 30 (pages 184-186) are used to describe machine conditions, dimensions, and its task description.

Performance Measurements (352)

All previous sections were related to variables affecting performance which should be considered in the evaluation process. All other things being equal, a comparison between two different machines should be made on the volume produced and cost per unit.

In this section, elements and variables influencing the performance throughout the study are considered. The final product should be identified and recorded by market names such as pine pulpwood, birch veneer, and so on, with the related volume of each type and the market or storage place, landing, or road side where products are delivered. The units used with related conversion factors should be indicated. These are basic for the calculation of production costs.

It is obvious that not only is the price of a veneer log higher than a pulpwood bolt, but that the care and time spent to produce it is also higher. Also where the product is sold is important. For example, if the wood is sold roadside, it means no hauling responsibility and planning for the producer. On the other hand if the buyer does not remove the material from road side or the landing on time, it may conflict with skidding or yarding, and/or storage. Form 31 (page 187) is used to record periodic system production.

Periodic Expense Report (352.1)

Machines come in different sizes and makes with different features. But those doing the same thing and performing the same function, may have different costs. The amount of fuel, oil, lubricant and other consumable supplies used differs from machine to machine and should be recorded carefully. Another source of expense is service material, and its interval of use, and its impact on variable costs. The service interval is very important not only because of costs of parts and labor but also the time that a machine is idle. Forms 32 and 33 (pages 188-190) are provided for periodic expense reports.

Detailed Recorder Analysis (352.2)

It is common practice that a machine assigned for a specific job, often temporarily moves to other jobs. This happens because of some need or emergency in other parts of the operation. As an example, a skidder may be used to help another vehicle which is stuck. There are so many interactions among different parts of the operation that the running time does not necessarily mean that the machine was doing the job to which it was assigned. A Service Recorder can be of great help to identify the changes in assignment. Cooperation between the operator and the observer is needed if these changes are to be noted. As sufficiently detailed analysis of the recorder discs can serve as a basis for measuring production rates. Forms 34 and 35 (pages 191-192) are used to record and analyze machine activities.

Cycle Timing and Work Sampling (352.3, 352.4)

There are several methods applicable to the study of harvesting practices for the measurement of the performance besides Service Recorders. Most common are Cycle Timing, Work Sampling (Random and Non-random), Elemental Time Study, and Photography and Instrumentation.

A cycle is the sequence of events which will be repeated by a man or machine during the process of its designed activities. The beginning and ending point of normal cycles should be identified. The cycle identifier must be precisely described. The primary important and influential variables should be selected and assigned to columns numbered 1-4. The start time of the first cycle is recorded in column one and magnitude of the variables estimated and entered under appropriate column. The end cycle time will be recorded which maybe the beginning of the next cycle. Any interruption should be recorded with comments describing them.

Cycle timing activity is a moderate intensity approach for machine productivity. The variables affecting machine performance like diameter, length, distance, slope, and other related influential factors can be identified and recorded for the activity of the machine being studied. There is no general set of independent variables adequate for every machine, therefore, space for four of them has been provided and it can be increased or decreased for any specific study. Prior to study and after careful observation of the machine activities, variables can be defined and coded by numbers. Estimates of the magnitude of each variable can be made and appropriate relationships can be developed. If the cycles are relatively short such as in chainsaw felling, a stopwatch should be used for monitoring cycle time. If the cycles are long (5 minutes or more) as with skidders, forwarders, or trucks a standard wrist watch may provide sufficient accuracy. It is recommended that a continuous cycle timing always be used to identify delays between cycles.

Work sampling can be used to measure the percentage of working and idle time of each individual person or machine under study. It can be employed to record many activities in the process. It does not provide as detailed information as elemental timing, but it is very simple and it may not even require a watch to record activity. Work sampling is based on random observation of individual members of the work force and it must be set up truly randomly. Any randomized method like a random number table can be used to start observations. It is not necessary to sample the crew or machines in the same sequence, but all the members and equipment should be recorded each time the observation is made. After a long period of time, the collected data will provide the ratio of work and idle time to the total scheduled time. Forms 36-38 (pages 193-196) are related forms for recording the observations.

Repair Report (352.7)

Repair is part of the life cycle of a machine, whether it is because of accident, abuse or normal wear and tear. It is necessary to indicate the component which needed repair, the type of repair, the amount of time to make the repair, and the people involved. This information will be used for estimating costs. The cause for repair whether it is accident, abuse, wear (with visual indications), fatigue (without visual indications), or any other reason should be reported. Preventive measures for future operations may be indicated. Form 39 (page 197) is used to record this information.

Modification Report (352.8)

If any equipment modification is carried out, it should be recorded with its nature, material used, reason for modification, and crew time involved. A record of the modification will help to understand the the differences between or among the same machines and to determine if such modifications improved the performance and were cost-effective. Form 40 (page 198) is used to record this information.

Machinery (370)

The last section deals with concept adequecy (370.01), design adequecy (370.02), service and repair consideration (370.03), safety and comfort consideration (370.04), and machine components (370.05) of machinery. Except for the machine components subsection, which is machine dimension and specifications, the other subsections are based on ratings from 1 to 10, with 10 being the perfect measure of the item on the machine. These ratings are made by the observer or someone knowledgeable and trained to evaluate the machine. The reason for assigning numerical values is to provide a broader range of ratings, and to provide a rating which will be relatively objective.

The machine design adequacy ratings are basically up to date applications of human factor or ergonomics to forestry machines and tools. They pertain to engineering design, safety and comfort, and the appropriateness of the machine or system for the existing environment and operational system. This section also deals with the concept of automation in forestry. Automation refers to the process of substituting machine activities for human activities, and brings attention to its appropriate use and consideration of man-machine relations. The increased interest in ergonomics has made it a universal part of evaluation methods. The increased scientific studies on vibration, noise, exhaust, and other variables have shown that careful consideration should be paid to the design process of machines to reduce deleterious effects of these factors on the human body. The benefit of these considerations are two fold. In one respect, it is a humanitarian approach which takes care of human well being on the job and complies with laws and regulations. Secondly, it is a beneficial approach with regard to higher output as a result of better and more comfortable design.

The rating approach for human factor design consideration, in some cases may seem to be subjective. But, over time, collecting more data, and training people, the values assigned, should be more realistic and the overall central tendency of compiled ratings on a machine could be used as the rated value for the machine. After many observations are made and ratings assigned to each element for the same machine by different people who have used the machine, then the average value over 10 can be the rated value used for that element. The same thing may be done for overal ratings of each part, as well as in each section, and the overall rating of the machine.

Concept Adequacy (370.01)

For a harvesting machine to be successful many requirements must be met and consideration given to different details. Besides marketing or fair price, a combination of some well known engineering procedures are essential to success. These engineering designs and layouts start at the very early stages of development, even before any drafting and drawing starts. The very first thing then, is the concept itself and the approach to achieve its adequecy. The factors included in concept adequecy are considered to be: product match, capital match, machine fit in the system, environmental restrictions, training requirements, contribution to the industry, support and communications, and flexibility.

1. Product match- Since the final product may be a full tree, tree length, shortwood, or other forms of process, the planning and machinery use for each, greatly differ from the others. For full tree logging, the skidders, loaders, and haulers are much larger than for shortwood operations. The application of a machine suitable for full tree logging of a shortwood product could increase the cost significantly. The form of the product is also important in that, it has to do with diameter and length and the quality of topping and debranching.

2. Capital match- For the same full tree or shortwood harvesting system, the capital investment and labor force are variables which play a significant role in their application. A machine development for a big operation, and a high investment, will not be suitable for a private landowner or small contractor, no matter how good the machine is and how efficiently performs. For the private land owner, a small machine with a few attachments may work well and if it matches the existing system, the possibility of success is high.

   Generally, the type of ownership and producer make great differences in organization, planning, and machines used. Most independent logging contractors attempt to select equipment which is suitable for a variety of harvesting conditions and within reach of their financial capabilities. It should be noted that the more expensive machines may be beyond the capability of most private contractors and may not be acceptable to them. Therefore, the capital requirements of these concepts should be carefully studied.

3. Machine fit in the system- There is a strong possibility of system failure if a machine does not

fit into an existing system or there are no other machines available or under development to support the system. If the machine is a misfit, its full potential can not be materialized and the existing system may not perform as expected. If back-up and attachments required for a machine are not provided fast enough, the purchaser will end up losing money. Design criteria can be initiated with the type of product expected and whether the machine itself is adequate to suit the existing system, or if other machines need to be developed or brought into operation in order to use the new machine.

4. Environmental restrictions- The possibility of failure will be strong if the machine does not perform well in its operating environment. For example a machine designed for hot climate only, may have difficulty in performing in cold temperatures. Different terrain, soil, stand type, and species may also limit application of certain machines.
5. Training requirements- It will be difficult to market a machine if it requires special scheduling consideration, planning, supervision, and mechanical training, or special tools, fuels and lubricants, and parts. Such requirements may also limit its adoption.

6. Contribution to the industry- Each new concept should have the potential to contribute to the industry, otherwise there is no need to invest large amounts of money, time, and effort in the venture.
7. Support and communications- It is important to avoid development of machines which require extensive support and communication back-up, they will increase cost and labor without any extra output.
8. Flexibility- The machine must be flexible enough to adapt to changes in site, stands, and other conditions.

Form 41 (page 199) is provided to record the foregoing information.

General Design Adequecy (370.02)

The next step is to consider design adequacy. This section is divided into seven subsections. These categories are overall considerations, power and transmission, chassis, cab, shielding, hydraulic system, and body construction material section. Each subsection, whether it is divided into specific areas or not, will be evaluated and rated based on specific and overall sufficiency. Therefore, an overall rating will be considered for the whole design and if it is adequate for the operation for which it is intended, the rating may be high, even if some subsections are rated low.

1. <u>Overall considerations</u>- The dimensions of the machine should be appropriate for the timber, terrain, and transport regulations. Over size or over weight machines, require special permission for each move which requires extra time, personnel, and adminstrative work. This may delay the whole operation and result in lost production.

   Installation of machine components should be easy and not require the services of a central repair facility. This means that if some parts of a component get damaged then the whole component can be replaced faster and easier, and the damaged component can be sent to the repair shop.

2. <u>Power and transmission</u>- A selection of components like engines or transmissions is not only a good marketing policy, but also creates larger possibilities of machine application. This is especially important for engine types which have good service facilities. Size of timber, type of species, and ground conditions, dictate the required power and transmission for a machine to allow comfortable operation and performance efficiency. The inadequate

power train is a waste of time and money and an over adequate power train is a waste of energy. The ability to adjust and interchange parts and components to provide adequate power for local use is a big advantage which establishes a wider market for the machine. Gear ranges should be such that low transmission gearing is provided to move a load over steep slopes and rough terrains without overheating the engine or damaging drive train, and also provide high transmission gearing for speed over level and gentle terrain.

3. Chassis- The rough conditions of forest operation call for strong components to withstand the shock loads and normal operating stresses. All components, especially those in direct contact with the terrain and timber, like tires and chassis or undercarriage should be designed and constructed to be able to operate effectively. Tires and tracks have different floatation abilities based on their size and construction. The variability of forest conditions requires the possibility of using a wider range of tires and tracks. If tires are used, enough room should be provided to install chains when required, expedite service, and replace or repair. Also for

tracks, access and easy removal should be considered. In addition, shields, guards to restrict entry of stone, mud, snow and woody materials between the track and rails or track and drive sprockets should be provided. The tire and track construction should be such that it can withstand the normal wear and tear, and abuse associated with operation and have less possibility of puncture for tires.

The width of the machine and height of the center of gravity are factors decisive to its tipping angle. The load affects the location of the center of gravity. Due to the position and the weight of the load, flexing and racking forces are not fixed and may vary considerably, and thus the tipping angle will vary. Care must be taken to protect the machine from roll over in both empty and loaded situations.

4. Cab and shielding- The cab is an integral part of the whole design and it needs to be located properly to provide enough protection, visibility for travel and operation, and easy access.

A major cause of extensive damage, is fire. Fire hazards are primarily related to short circuits and the exhaust system. The electric wires should be designed to avoid areas of debris, oil, and spilled fuel. Exhaust systems should be routed under the hood and away from the machine with installation of spark suppressor and tight connections between the manifold and exhaust pipe. Fire may start by engine overheating, and brake heating as well. The machine should be designed to avoid flat areas and openings which accumulate debris near these parts.

5. Hydraulic system- Each component of the hydraulic system should be easily replaced. Most any problem with the hydraulic system means stopping the operation. Therefore, if the location of valves, cylinders, pumps, and other parts of the hydraulic system are conveniently reached and easily opened and replaced downtime will be minimized.

6. Steel section- There are many parts and sections in harvesting machines which are welded together. The quality and workmanship of all weldings should be very high. Any break or damage to the welds, may cause downtime. Special attention should be paid to uniformity of the welds, installing wear plates at proper points where an unusual amount of abrasion or rubbing is anticipated, and the ability to replace or repair wear plates.

Form 42 (page 201) is used to record general design adequacy information along with respected ratings.

General Service and Repair Consideration (370.03)

There is a distinct difference between "maintainability" and "maintenance". The first refers to principles of design which are basic to future equipment repair. The latter refers to the process and technical problems of keeping equipment in an operational state or repairing the damaged unit once the equipment is in use (Crawford and Altman, 1972). Maintainability has great effect on the maintenance process. If a unit never fails, there will be no need to repair it, and if it fails often, then the down-time to repair or replace it, will increase. The consideration here is to daily service, periodic service, and service compatability.

1. Daily service- The concept of service and keeping the parts in good shape, plays a great role in maintaining equipment. The need for access and ease of repair or service increases as the frequency of doing it increases. If a part needs daily service, then it should be easily accessible, if it isn't, the tendency to forget the job is high which may lead to extensive damage to the unit and extended downtime.

The service points like fuel, engine oil, oil, coolant, air filters, batteries, and hydraulic filter and reservoir are those that need daily checking. Therefore they should have the easiest and most comfortable position to access.

2. Periodic service- Parts which need periodic service should be accessible and the maintainability engineer should try to make them as a group with the possibility of servicing several points through a common part. In addition, the adequate comfort and protection for the mechanic doing the service should be provided.
3. Compatability- As it was stated for tools and parts, supplies such as oil, lubricants and filters should be unified and the need for special supplies minimized, otherwise the cost of inventory will go up or long waiting periods for delivery will be encountered.

The information and rating regarding service and repair are in the form 43 (page 204).

General Safety and Comfort Consideration (370.04)

Safety and comfort are important not only to avoid accidents, which in harvesting can easily be fatal, but also to increase the productive time and efficiency of the system. In many industrialized countries accident preventive measures are mandatory and required by law. The obvious reason for concern about safety, besides the humanitarian aspect of it, is if an accident occurs, the system will be down and the consequence depending on the seriousness of accident and time to recover, differs. In any case, it has a negative effect on production.

Comfort, is also of concern because if the operator is not comfortable, he or she will find excuses to avoid the machine. Measures for safety and comfort, affect almost all units and components in a machine, because directly or indirectly, they impact the system and/or operator. The features considered are categorized in different units as: access, cab, seat, vibration, seat/control relationships, visibility, lighting, sound, hazard prevention, associated crew safety, fire and accident protection, and transport considerations.

1. Access- Considering the size of the harvesting machine which requires climbing into the operator's compartment, and the fact that operator may have to

get in and out frequently, makes it important to provide easy, comfortable, and safe access. This includes ladders, steps, handholds, catwalks, railing, gratings, doors, and gates when needed, to be adequate and appropriate to prevent slippery and unsafe access. The door or gate should be easy to open and close.

2. Cab and shielding The cab should be constructed such that it not only meets ROPS FOPS (Roll Over and Falling Objects Protection Structures) specifications, but also provides protection from foreign matter entering the cab. Also minimizing protrusions and sharp angles in the cab; preventing dust, fuel and exhaust vapors entering the cab; and, avoiding the fuel, fluid and wiring through the cab as much as possible will make it safer to work in. Protection from heat, cold, wind, precipitation and control over them should also be provided. The cab should also be isolated from high and low frequency vibration. By all means, the effect of noise should be minimized. And finally, the cab must be designed with adequate escape hatches in case of fire and roll over.

3. Seat- Human engineering principles call for a comfortable reach to the control levers and panel. The seat should be positioned such that the operator feels comfortable with adequate protection and visibility. The seat itself should be properly anchored and seat belts provided. The seat should be adjustable in all four directions (forward, backward, up, and down), and also should have a suspension system with a wide range of adjustment for the comfort of people of different weights. The materials and upholstery should not clog the air movement and accumulate dew or atmospheric moisture. If the machine is designed for operations involving hand and finger movements, providing arm and head rests is a good idea to make the operation less tiresome.
4. Vibration- Studies have shown the bad effects of vibration on exposed bodies. Two types of vibration are of primary concern which are "sinusoidal vibration" and "random vibration". The first one is characterized by its regularity and may be a single sine wave with particular frequency or a combination of several sine waves of different frequencies. The latter is characterized by irregularity and unpredictablity and is the most common type of

vibration which influences the body. There are pronounced physiological and psychological effects resulting from exposures to whole body vibration. The physiological effects include a slight acceleration in the rate of oxygen consumption, pulmonary ventilation and cardiac output. There are evidences of an inhibition of tendon reflexes and an impairment in the ability to regulate the posture, possibly by actions through both the vestibular and spinal reflex pathways. There has been evidence of effects on visual acuity and performance at various levels of motor activity and task complexity during exposure to whole body vibration (Soule, 1973). It should be noted that whole body vibration is the most common vibration caused by forestry machines. Harvesting machines are subject to the vibration generated by running big engines. Also, there is a constant source of shock because of movement over the rough ground conditions. Every attempt should be made to reduce the vibration. For vibration which cannot be avoided, the seat should be well sprung and insulated from shock.

5. <u>Seat/control relationships</u>- Having the seat adjustable will make it easier to reach the controls.

But consideration also must be paid to control grouping and location. Before a control is selected, information is needed regarding the function of the control, the requirements of the control task (precision, speed, or force needed), the informational needs of the operator, the requirements imposed by the work-place (like cab space and limitations), and the consequences of inadvertent or accidental operation of the control. The general rules to follow for designing the control, based on the information collected, are assigning precise and rapid controls to hands and large continuous forward applications of force to feet; designing the type of controls with their location and orientation to comply with the selected movement; selecting controls that can be easily identified; and finally, grouping all functionally related controls to reduce reaching movements.

6. Operator visibility- Attention must be paid to ensure an adequate field of vision for the operator to see all around and be able to see the crew members and their body positions with regard to wood and machine movements. Field vision may be blocked by some attachments, or conditions be such that better vision

is required. The components should allow modifications to be carried out with a minimum of problems. Obviously, if windows and glasses are used in the cab, defrosters, washer, and wipers should be provided. Back and side mirrors, like in any other vehicle are necessary for road travel.

7. Lighting- Usually, there is no need for lighting during the day when working in the woods. But if the machine is used for travel or night operation, lighting is imperative and it should be enough and in proper location. This includes both the vision and the signal lights. Lighting should provide enough illumination and the distribution of it must be such that to minimize glare. The wiring system of the lighting should be well protected. Because if cut or disconnected, there is no way to continue the work and any movement may be dangerous. In addition, the cost of night operation is higher, so the related downtime will be more costly.

8. Noise- National standards in different countries may have set the maximum allowable noise level and duration slightly at different levels or scales, but noise exposure for both operator and associated crew members are recognized. Proper action to comply with

minimum exposure to noise either by isolating the sound source from the cab or by using ear protection should be undertaken. It is necessary to know whether the machine is designed such that there is no need for ear protection for operator or crew.

9. Hazard prevention- There are several measures to consider at design stage that are concerned with hazard prevention. For electrical parts, high quality connectors and wiring should be used to avoid the effects of high and low temperature, oil and other solvents, and moisture. Protection for all electrical parts are essential. Labels on high voltage points and automatic circuit breakers or locking access to unauthorized personnel are necessary. It is quite important to equip the machine with an emergency brake strong enough to hold the machine on the steepest expected slope with the possibility of adjusting its control position for use by different operators. Also necessary, is a dead-man switch on the machine to block automatic functions when the operator leaves the cab. Other points to consider, are marking the hazardous areas and designing the machine such that cleaning and servicing are carried out easily.

10. Associated crew safety- A clear, constant contact between operator and crew members, is vital and a well understood line of communication should be established with clear visibility all around the machine for operator. Blind spots should be minimized at the design stage and if there is any, it should be known and understood by the operator as well as crew members. The dead-man switch reffered to earlier, again, will be helpful to disengage clutches and automatic functions when the operator is not in the cab and especially when servicing the machine. It is a must for harvesting machines to have clear, visible and loud audible signals.
11. Fire and accident protection- If set on fire, especially in the dry season, the damage to a machine can be high with the risk of forest fire and injuries or fatal accidents to the crew and operator. To minimize the possibility of such accidents, the exhaust manifold, pipe and muffler, should be properly located and be protected adequately. The direct spillage of fuel or oil to the exhaust system when servicing and changing filters should be avoided which means the location of exhaust should be away from filters'areas. There should never be any place

around the exhaust area which can be a center of debris accumulation. The location of air intake, especially with regard to gasoline and light fueled equipment should be located such that prevent ignition by backfire of surplus fuel in the carburetor, the engine compartment, or oil and other flammable materials accumulated in the engine area. The fuel and hydraulic oil tanks should be located to avoid discharge caused by overfilling or heating. Fuel should not be accumulated on the machine, in the machine cavities or in the operator area. The tanks should be properly protected from impact, piercing and vibration.

12. Transport consideration- Many harvesting machines are larger than the maximum allowable sizes for transportation on public roads. It is necessary that such machines be able to be separated or easily broken down to several pieces to conform with regular dimensions. If possible, the machine should be self propelling for moving from one site to another. If the machine is driven on the highway, the steering should be adequately stable and the machine must be equipped with necessary signals. Enough braking power for traveling at highway speeds is also required.

All information and related ratings are compiled in the form 44 (page 205).

Machine Components (370.05)

This last section records machine components and specifications. It is not used for rating but merely records the machine specifications and its technical characteristics in order to identify the machine and its attachments, transmission type and model, drive train, undercarriage, steering, and brakes. This information is provided by the company making the machine or components and attachments. They are used for transportation, modification, repair, or attachments to be added to the machine and for application and use of the machine for different locations and loads. Form 45 (page 209) is used to record this specifications.

FIELD TESTING

In order to assess the practicality of the data collection methods and suggested formats, a two week high intensity test of an FMC-180 CA tracked skidder on steep terrain in the Appalachian mountains was conducted. The purpose of the trial was to see if this machine could be effectively used on steep terrain normally relegated to cable systems. The two week study also afforded the opportunity to include collection of information on factors and provide data for analytical purposes and developing predicting equations.

The USDA Forest Service timber sale was contracted by S. A. Bennett Logging Company who agreed to utilize the FMC-180 machine in his operation. The company already had a system in production which included 1 Caterpillar 518 Cable Skidder, 1 Prentice 210 Knuckleboom loader, 2 Tandem Trucks, 2 Tri-Axle Trucks, and 1 Tractor- Semi-Trailer. The crew consisted of two chainsaw fallers, 1 feller/chokerman, 1 FMC operator, 1 Cat operator, 2 bucking/unhooking people, and 5 truck operators. Bennett was active as one of the crew, mostly as the loader operator.

The logging unit to be harvested was compartment 5057, Graig County near New Castle, Virginia. The unit stands were 3, 7, and 14 which included 40 hectares of hardwood stand with 104.3 cubic meters of sawlogs per hectare . The stand composed of 50% saw timber and 50% pulpwood. The unit on steep terrain contained 10.93 hectares (27 acres) with a total gross volume of 179.6 cubic meters per hectare (15.4 MBF/acre) based on an estimate of Jefferson National Forest personnel.

Forest Model- A plot of four quadrants with a total area of 0.10 hectare (1/4 acre) was established and trees were numbered, all information on the stand and area was recorded. Time Studies were conducted for this area when felling and skidding were in process.

The process was started with timber-fallers to fell, limb, and top. The chokers were set by the choker setter and the FMC operator assisted him whenever was necessary. The FMC spooled 30.5 meters (100 feet) of 1.9 centimeter (3/4 inch) cable for the skidding operation and 6 chokers of 1.4 centimeter (9/16 inch) which were attached to the winch line with slider hooks. The buckers, at the landing, released (unhooked) the logs then measured and bucked them. The sorting was done by the loader operator. The truck drivers, while waiting for their truck to be loaded, were assisting in bucking, measuring, or felling trees.

The Walking Quotient was measured first by pacing 30 meters (100 feet) on level road and then several pacings in different directions (uphill, downhill, across, and on contour lines) on the Forest Model for the same 30 meters on each direction. The average of these pacings were used for a Walking Quotient value in the working area.

For demonstration purposes the information collected during one day's operation is presented in the Appendix. The analyses are based on the total data collected during the study.

For the evaluation sections on human factor considerations, Mr. Bennett and two operators were asked to fill out the forms. Due to the short period of machine use and its newness many details which needed further examination were not answered. It is appropriate to emphasize that to properly evaluate a system more time and a thorough study of the system is required. However, two operators and Mr. Bennett agreed to rate the FMC-180 and Caterpillar 518 machines. For demonstration purposes only the evaluation of the FMC operator is presented in the Appendix. It is important to note that the FMC-180 was a prototype unit which was not equipped with many features like doors, air conditioning, and lights. The ratings are merely the opinion of the operators.

It must be emphasized that in the process of selecting a system, profitability is the main concern. To find the productivity and ultimately the economic feasibility of a system, a work study has to be carried out and many records filed. During the study, Service Recorder Analysis, Cycle Timing, Elemental Time Study, and Work Sampling were employed. The results including a regression equation developed for FMC skidding time based on Elemental Time Study are presented.

The Service Recorder was used on the FMC for for five days. Working and idle times were identified during running time. Since the machine was new and servicing was good, there was no problem with mechnical delays. The only problem related to idle time was due to waiting at the landing to unload. Following is a summary of results taken from the recorder disks:

Total Time Recorded: 26 hr:22 min: 20 sec

-Working Time: 14 hr:35 min:10 sec

-Idle Time: 13 hr:47 min:10 sec

Total Number of turns: 113

Utilized Time: 14.586/28.372=51.4%

Delay (Idle) Time: 13.786/28.372=48.6%

Time per turn: 15 min:4 sec

Cycle Timing was employed for chainsaw operation. The cycle for felling was defined as the time to start the chainsaw, move to the tree, cut the tree, limb and top, and move to the next tree. The total number of cycles observed was 21 and the results are summarized as:

Total Cutting Time: 20.67 minutes

Average Cutting Time: .984 minutes

Total Delimbing Time: 22.39 minutes

Average Delimbing Time: 1.07 minutes

Total Clearing Time: 23.44 minutes

Average Clearing Time: 1.12 minutes

Total Delay Time: 78.39 minutes

Average Delay Time: 3.73 minutes

Average DBH: 13.7 inches

Average DGL: 20.29 inches

Elemental time study was conducted on felling to find the relationship between cutting time and DBH. In this study, three observers conducted the study with deciminute stop watches. The observations were submitted to SAS Release 82.4 for simple regression analysis. This analysis is set up below:

Cutting Time= -0.50334112 + 0.11855139(DBH)

The statistics summary is:

Source	DF	Sum of Squres	Mean Square	F Value	Prob>F
Model	1	20.08891384	20.08891384	56.61	0.0001

Error	49	17.38776067	0.35485226
C Total	50	37.47667451	

Root MSE: 0.59569477

R-Squared: 0.536038

This means that the regressor DBH contributes significantly (=0.0001) to the model. Furthermore, about 54% of variation in cutting time is explained by DBH variable.

Elemental Time Study was used for recording skidding production of the FMC and time was measured by a centiminute stop-watch. Five basic elements were defined in the skidding cycle. The five elements were travel empty, hook, winch, travel loaded, and unhook. Travel empty began when FMC FT-180 left the landing and ended when machine was positioned with brakes on and the winch was about to be released. Hook began when winch was released and the chokerman was pulling it to the logs and attaching the hook to the chokers and ended when the chaser signaled the operator to spool the winch. Winch started when the spooling was started and ended when the arch of the machine was upright, with the skid on the machine, and ready to move. Travel loaded started when the skid was on the back of the machine and moving started with load and ended when the machine was at the landing. Unhook began as the machine arrived at the landing and ended when the machine was free from load and leaving the landing for next cycle. Delays were recorded at any stage of the operation where they occured.

Variables considered effective were slope, skidding distance, number of logs/turn, and weight of the turn load. On each trace the slope was measured in percent and recorded while the skidding distance was measured separately for each turn. The number of logs delivered to the landing for each turn were counted. To find the weight, the prediction equation models developed by Ford, Stuart, and Walbridge (1976) based on the hardwoods in the Appalachian region of Virginia were employed. Since the logging was carried out during fall, the average Product Weight (PW) of summer and winter was used to calculate the log weight. The equations used were as follow:

Hardwoods Sawlogs Other Than Oak

1. Summer: $PW=B1(DBH^2 \times Merch.\ Hgt)+ B2(DBH)$
   where B1=0.1943, B2=7.9561

2. Winter: $PW=B0+B1(DBH^2 \times Merch.\ Hgt)+ B2(\log(DBH^2 \times Merch.\ Hgt))+ B3(DBH)$
   where B0=6.5147, B1=0.1146, B2=-224.9086, B3=129.6815

White Oak Sawlogs

1. Summer: $PW= B1(DBH^2 \times Merch.\ Hgt)$

   where B1=0.2173

2. Winter: $PW=B1(DBH^2 \times Merch.\ Hgt)+ B2(DBH)$

   where B1=0.1650, B2=15.3539

Scarlet Oak Sawlogs

1. Summer: $PW=B1(DBH^2 \times Merch.\ Hgt)$

   where B1=0.2139

2. Winter: $PW=B1(DBH^2 \times Merch.\ Hgt)$

   where B1=0.2150

Chestnut Oak Sawlogs

1. Summer: $PW=B0+B1(DBH^2 \times Merch.\ Hgt)+ B2(DBH)$

   where B0=-268.7308, B1=0.1215, B2=67.1925

2. Winter: $PW=B0+ B1(DBH^2 \times Merch.\ Hgt)+ B2(DBH)$

   where B0=-556.7856, B1=0.0906, B2=116.5264

Softpulping Hardwood Sawlogs and Pulpwood

1. Summer: $PW=B1(DBH^2 \times Merch.\ Hgt)+ B2(DBH)$

   where B1=0.1554, B2=9.2715

2. Winter: $PW=B0+ B1(DBH^2 \times Merch.\ Hgt)+ B2(DBH)$

   where B0=-342.5727, B1=0.1052, B2=77.0955

Hardpulping Hardwood Pulpwood

1. Summer: $PW=B1(DBH^2 \times Merch.Hgt)+ B2(DBH)$

   where B1=0.1682, B2=9.9255

2. Winter: $PW=B1(DBH^2 \times Merch.\ Hgt)+ B2(DBH)$

   where B1=0.1928, B2=7.9173

Oak Sawlogs Not Previously Categorized

1. Summer: $PW=B1(DBH^2 \times Merch.\ Hgt)+ B2(\log(DBH^2 \times Merch.\ Hgt))+ B3(DBH)$

   where B1=0.1394, B2=-192.8812, B3=105.9461

2. Winter: PW=B1(DBH^2 x Merch. Hgt)+ B2(log(DBH^2 x Merch. Hgt))+ B3(DBH) where B1=0.1008, B2=-270.0543, B3=154.7596

To analyze the collected data to develop the time dependent prediction equation based on the variables defined, the data was submitted and run under release 82.4 of SAS (Statistical Analysis System) at VA Tech. To select the "best" regression equation with regard to candidate regresors for the data set, variable selection procedures were used. Obviously, none of the these procedures are guaranteed to produce the "best" regression equation for a given data set. The criteria used for evaluating subset regression models were coefficient of multiple determination (R^2), Mallows' CP statistic, and Allen's PRESS. Since the intention of developing the regression equation was for prediction, emphasis was on PRESS, because it has intuitive appeal for a prediction problem. The following equation was selected based on the low values of PRESS and CP while maintaining a high R^2.

Total Time= 78.559458 + 0.024818 (Skidding Distance)

- 1.868883(Slope) - 0.437599(Pieces) + 0.0002652(Weight)

Note: skidding distance in feet, slope in percent, and weight is in pounds, because the equations used to calculate weight was based on pounds.

The information available from SAS can be summarized as:

Dependent Variable: Total Time (TT)

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	4	369.462	92.365431	15.186	0.0001
Error	40	243.296	6.082409		
C Total	44	612.758			

Root MSE: 2.466254

R-Squared: 0.6029

Adjusted R-Squared: 0.5632

CP: 4.2425

PRESS: 335.279

The P-Value of 0.0001 shows that the regressors are contributing significantly to the model. About 60% of the variation in total time of skidding is explained by the selected variables.

Machine Rate calculations based on preliminary results obtained from recorded information by the Bennett Logging company and FMC company, are presented as:

Assumptions

Purchase Price (P): $ 135000

Salvage Value (S) $: 35000

Life in years (L): 5

Scheduled hours/year (H): 2000

Interest, Taxes, and Insurance% (I): 24

Fuel and Lube $/Productive hour (F): 3.85

Tires and Tracks $/Productive hour(T): 12.00

Repair and Maintenance $/Productive hour (R): 9.52

Labor Rate $/hour (LR): 4.50

Labor Fringes% (LF): 35

Expected Utilization% (U): 80

Calculations

Depreciation/hour: D=(P-S)/(L*H)= $10.0/Scheduled hour

Average Fixed Investment: A=(P-S)*(L+1)/2L+S=95000

Interest, Taxes and Insurance: ITI=(I*A)/H=$11.40/Scheduled hour

Total Fixed Cost: TF=D+ITI=$21.40/Scheduled hour

Fuel and Lube Cost (F): $3.85/Production hour

Track Cost (T): $12.00/Productive hour

Repair and Maintenance (R): $9.52/Productive hour

Total Variable Costs (TV): TV=E+F+T+R=$25.37

Variable Cost/Scheduled hour= TV*U: $20.30/Scheduled hour

Total Machine Cost (TMC)

TMC=Total Fixed Cost+Variable Cost.Scheduled hour

TMC=$41.70/Scheduled hour

Labor Cost: LR(1+LF/100)=$6.075/Scheduled hour

Total Machine and Labor Cost= $47.80/Scheduled hour

Tota Machine Cost Per Day=$47.80/Sch.Hr. * 8hr./day

Total Machine Cost=$382.40/day

Using the Total Machine Cost, Total Time equation, and assuming average values for independent variables of skidding distance, slope, number of pieces, weight, and delay time per cycle, the =average cycle time and cost per unit of timber delivered to the landing by the FMC can be presented as:

Average Total Time/turn= 10.28867 min./turn

Average Total Time/turn with Delay= 12.21867 min./turn

Total Turns/hr= 5

Total Turn/day with 80% utilization= 5* 8* 80%= 32 turn/day

Average Weight Skidded/turn=7291 lbs.

Total Average Weight Delivered at the Landing= 233312 lbs.

Cost per unit= $1.64/thousand lbs.

Overall, during five working days application of service recorder, the following statistics were compiled:

Total Time Recorded- 28 (hrs):22 (min):20 (sec)

Utilized Time- 14 (hrs):35 (min):10 (sec)

None Productive Time- 13 (hrs):47 (min):10 (sec)

Total Number of Turns Skidded: 113

Utilized Time= 51.4%

Idle Time= 48.6%

Work Sampling or Ratio Delay method was employed and all activities involved in the operation were recorded. The random sampling was conducted for 6 hours with the starting time of each sequence of observation chosen randomly. The study covered all machines and people working in the area. The observations can be summarized as:

Total Number of Observations: 18, and the ratio delay for each individual individal or machine are as following:

Powersaw Operators number one: 33.3%

Powersaw Operator number two: 33.3%

Powersaw Operator number three: 38.3%

Choker Setter number one: 61.1%

Choker Setter number two: 61.1%

Bucker number one: 22.2%

Bucker number Two: 27.8%

FMC Tracked Skidder: 5.6%

Prentice Loader: 2.8%

Caterpillar Wheeled Skidder: 27.8%

Hauling Trucks number one: 11.1%

Hauling Trucks number two: 77.8%

Hauling Trucks number three: 55%

Hauling Trucks number four: 38.9%

Hauling Trucks number five: 61.1%

Clearly, the loader had the lowest delay ratio, working almost 97% of the time, followed by the FMC which worked 95.4% of the time. The lowest working time belonged to hauling trucks which with their high costs, indicates that further study and the possibility of reorganizing the operation by adding more loader capacity is worthwile. Eventhough, these values are based on a short study, a two week study conducted later leads to the same conclusions. The wheeled skidder, as well as powersaw operators, were not fully utilized because of loading problems at the landing. In addition, removal of the aforementioned bottleneck, would offer the possibility of improving crew utilization.

Also, a Non-Random work sampling method was used on 2 chainsaw operators and one choker setter working as a team. The observation interval was every 2 minutes for 2 hours. Following table shows the summary of all activities during the period. One of the operators was basically helping the FMC operator.

NON-RANDOM SAMPLING SUMMARY

	Chainsaw Operator 1	Chainsaw Operator 2	Choker setter
Delay%	40	45	70
Choker Setting	6.67	0	20
Brush Cutting	5	3.33	0
Felling	10	18.3	0
Delimbing	8.33	13.3	0
Chain Replacing	16.67	0	0
Filing	1.67	8.33	0
Move to next tree	6.67	8.33	0
Trace Layout	1.67	1.67	1.67
Guiding FMC	0	0	5
Clearing	0	0	1.67
Move Gas Can	0	0	1.67

This summary shows that the choker setter had the most idle time and only 20% of the time was setting chokers. Between the two chainsaw operators the working time was fairly equal. However, chainsaw operator 1 spent 16.67% of his time replacing his saw chain which raises the question of having a third powersaw as spare. In this case, the choker setter could replace the saw chains, sharpen them, and fuel the saws during his idle time.

RESULTS AND DISCUSSION

A standard procedure for data collection was developed to serve as an international standard for the evaluation of harvesting machines and systems. The format logic was based on an in depth study of data collection methods used by research organizations throughout the world and modification of the American Pulpwood Association-Harvesting Research Project (APA-HRP) cooperative testing procedure. The method consists of forty five forms that are categorized into four major sections. The classifications closely follow the Oxford Decimal Classification for Forestry.

The first section is devoted to an environmental description (306.10) which contains twenty forms. These forms are used to record weather conditions (306.101), ground conditions (306.20), working conditions (306.30), stump area processing (306.32), stump area transport conditions (306.33), strip road/skid trail conditions (306.34), landing or roadside conditions (306.35), hauling or transport (306.36), road limitations (306.363), terminal (306.37), stand conditions (306.40), check plots (306.42), volume table development (306.43), Forest Model (306.440), residual stand damage (306.451), and harvesting strategy and history (306.50).

The second section with ten forms is used for system description (312). These ten forms are related to crew organization and safety (312.00), employee description (312.10), tasks and skills (312.11), periodic pay and production (312.12), accident or illness report (312.13), resignation/termination report (312.14), system description (312.20), material flow (312.21), machine conditions and dimensions (312.22), and machine or task description (312.23).

The third section is devoted to performance measurements (352) with ten forms used for recording the periodic system description (352.0), periodic expense report (352.1), detailed recorder analysis (352.2), shift recorder analysis (352.2), cycle timing (352.3), work sampling (352.4), elemental time study (352.5), machine repair report (352.7), and modification report (352.8).

The final section is machinery (370). Five forms are developed in this section and are used for ratings and specifications. These five forms are concept adequacy (370.01), general design adequacy (370.02), general service and repair considerations (370.03), general safety and comfort considerations (370.04), and machine components (370.05).

It is of particular importance to note that in most cases only selected forms are used for the data collection. The number and type of forms used will depend on the intensity or level of the study. For example:

1. Low intensity (level-one) data collection is employed on a daily or weekly basis. These data are concerned with the operation's productivity, labor, and environmental conditions. The purpose of these studies is to develop a history of system performance, effects of the environment and personnel on the operation, compile cost and availability information, and determine labor skills and turnover.
2. Medium intensity (level-two) data collection is normally used on a regular but intermittent basis throughout the study. Periodic pay and production records, accidents or illness reports, resignation/termination reports, consumable supplies and service materials reports, repair and modification records, service recorder studies, work sampling, and cycle timing are included in this level. The purpose is to provide detailed records of the factors which affect system productivity and to provide a basis for statistical analysis. Documentation of the wear and tear of equipment as a result of operation is included in this level.

3. High intensity (level-three) data collection is used whenever detailed information for mathematical relationship development or ergonomic considerations are needed. These studies include elemental times, volume table development, soil bearing capacity, fuel consumption, and ergonomics. The purpose is to provide very detailed descriptions of the operation in order to develop prediction equations of productivity, estimate of machine life, evaluations of operator proficiency and interaction between man and machine.

Following table shows the forms that would be normally used for the different intensities (levels) of data collection.

Forms used at different levels of data collection

	level 1	level 2	level 3
Environment Description	X		
Ground Condition	X		
Working Condition	X		
Stump Area-Processing	X		
Stump Area-Transport	X		
Strip Road/Skid Trail	X		

Landing or Road-side	X		
Hauling/Transport	X		
Road Limitation		X	
Terminal		X	
Stand Conditions		X	
Check Plots		X	
Volume Table			X
Forest Model			X
Residual Stand Damage			X
Harvesting Strategy		X	
Harvesting History		X	
Crew Organization		X	
Employee Description	X		
Tasks and Skills	X		
Periodic Pay and Production		X	
Accident or Illness Report	X		
Resignation/ Termination	X		
System Description		X	
Material Flow	X		
Machine Conditions and			

Dimensions		X	
Machine or Task Description	X		
Periodic System Production		X	
Periodic Expense Report,Consumable		X	
Periodic Expense Report,Service		X	
Detailed Recorder Analysis		X	
Shift Recorder Analysis		X	
Cycle Timing		X	
Work Sampling		X	
Elemental Time Study			X
Repair Report		X	
Modification Report		X	
Concept Adequacy			X
General Design Adequacy			X
General Service and Repair Considerations			X
General Safety and Comfort Considerations			X
Machine Components			X

In order to test the practicality of the forms developed for data collection, they were used to conduct a study of a prototype tracked skidder on steep ground in the Appalachian Mountains. The field test resulted in some modifications of the forms with regard to recording and filing procedures. The purpose of the modification was to make recording and filing methods easier and faster. During the test, a high intensity (level-three) data collection was conducted on a prototype FMC skidding machine model FT-180. This machine was incorporated into an already operating system as an alternative to cable yarding. Preliminary findings show that this machine might be employed on steep terrain at lower costs than cable yarding. However, further study is needed to determine whether the machine is affordable as a component of a system for steep terrain skidding and soil disturbance is as minimal as was indicated.

The data collection forms along with the guidelines for their use are compiled as a separate volume or "Field Manual". The Manual was submitted to the supporting organizations of the International Energy Agency (IEA) which includes Canada, New Zealand, Sweden, and the United States for its review and critique. To date, the reviews from the United States and New Zealand have been recieved with their supportive comments. Their suggestions were basically related to minor details which did not require any major changes to the forms. When the critiques of Sweden and Canada are recieved, their suggestions will be incorporated into final draft of the Field Manual.

To facilitate documentation and exchange of information regarding the evaluation and analysis of harvesting machines and systems accross international borders, it is suggested that a microcomputer program be developed. This program will file and edit the recorded field data, runs basic statistical analysis, and prepares the data for submition to prepackaged advanced statistical analysis.

During the past decade, an increasing attention has been paid to application of ergonomics to harvesting systems. Because of its importance and its implications for safety and work performance, it seems to be appropriate to recommend that an independent center be established to conduct the human factor design considerations. There are already many standards on different parts of the machine design which are examined in different countries throughout the world especially in Scandinavian countries. Based on the studies carried out in the area of human factor, quite a few features of a machine can be objectively evaluated. These features include such factors as position and characteristic of seat with certain range of adjustments in different directions, noise level and operator exposure limit, cab design being FOPS and ROPS, hydraulic system design and hoses specifications, and many other parts.

This center can serve as an authority to evaluate machines. Thus, newly produced or at prototype stage machines will be tested by the center and the obtained information can be made available to the interested users. The users in turn, can fill out the machinery forms (forms 40-45) and send them back to the center along with their evaluations for compiling and providing rating values.

SUMMARY AND CONCLUSIONS

The objectives of this research were two fold. The first was to develop a data collection method to serve as an international standard for the evaluation of harvesting machines and systems throughout the world. The second was to test the adequacy of the method for international use by requesting a critique by the supporting member countries of the International Energy Agency (IEA) and using the method to evaluate a prototype tracked skidder on steep terrain of Appalachian Mountains.

An in depth study of data collection techniques by research organizations throughout the world was made to identify those factors which most affected the performance and productivity of harvesting machines and systems. This study revealed that the majority of research organizations considered environmental, mechanical, personnel, and design factors to have the most influence; however, there did not appear to be any standardization in measurement and reporting methods which made it difficult to compare studies from different forest regions.

The American Pulpwood Association-Harvesting Research Project (APA-HRP) cooperative testing procedure was used as a basis for the development of a standardized method of data collection. The logic used to develop the forms for international use incorporated the influential factors used by other research organizations and modifications and additions to the aforementioned cooperative testing procedure.

In all, forty five forms were developed within the four major sections of Environmental Description, System Description, Performance measurements, and Machinery. It is of particular importance to note that in most cases only selected forms are used. The number and type of forms used depends on the intensity or level of the study.

The practicality of the forms were tested on an in depth study of a prototype tracked skidder on steep terrain in the Appalachian Mountains. This study was helpful in modifying certain forms to make the required recording easier and faster. The analyses of the data obtained with the use of these forms indicated that the prototype machine might be used for skidding on steep ground at lower cost than cable yarding. However, further study is needed to determine whether the machine is affordable as a component of a system for steep terrain skidding and soil disturbance is as minimal as was indicated.

The data collection forms along with the guidelines for their use are compiled as a separate volume or "Field Manual". The Manual was submitted to the supporting organizations of the International Energy Agency (IEA) which includes Canada, New Zealand, Sweden, and the United States for its review and critique. To date, the reviews from the United States and New Zealand have been recieved with their supportive comments. Their suggestions were basically related to minor details which did not require any major changes to the forms. When the critiques of Sweden and Canada are recieved, their suggestions will be incorporated into the final draft of the Field Manual.

To facilitate documentation and exchange of information regarding the evaluation and analysis of harvesting machines and systems accross international borders, it is suggested that a microcomputer program be developed. This program will file and edit the recorded field data, runs basic statistical analysis, and prepares the data for submition to prepackaged advanced statistical analysis.

During the past decade, an increasing attention has been paid to application of ergonomics to harvesting systems. Because of its importance and its implications for safety and work performance, it seems to be appropriate to recommend that an independent center be established to conduct the human factor design considerations. There are already many standards on different parts of the machine design which are examined in different countries throughout the world especially in Scandinavian countries. Based on the studies carried out in the area of human factor, quite a few features of a machine can be objectively evaluated. These features include such factors as position and characteristic of seat with certain range of adjustments in different directions, noise level and operator exposure limit, cab design being FOPS and ROPS, hydraulic system design and hoses specifications, and many other parts.

This center can serve as an authority to evaluate machines. Thus, newly produced or at prototype stage machines will be tested by the center and the obtained information can be made available to the interested users. The users in turn, can fill out the machinery forms (forms 40-45) and send them back to the center along with their evaluations for compiling and providing rating values.

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Appendix A

FORM 1

306.10 Environment Description

Study ID: (1)
Date: 9/30/83
New (x), Revised---

101 Weather Conditions

101.1 Temperature (celsius)
101.11 Maximum: 17
101.12 Minimum: 13
101.13 Average: 15
101.21 Wind velocity
a. no wind or still (<2 km/hr)
(x)b. light wind (2-20 km/hr)
c. moderate wind (20-40 km/hr)
d. high wind (>40 km/hr)
101.22 Wind Direction: S
101.23 Wind Consistancy
a. constant
b. irrigular
(x)c. occasional
101.3 Relative Humidity % : 57
101.4 Precipitation

101.41 Type	101.42 Duration
a. none	------- hrs
b. drizzle (very light rain)	------- hrs
(x)c. rain	5.5 hrs
d. hail	------- hrs
e. sleet	------- hrs
f. snow	------- hrs
g. other	------- hrs

101.43 Accumulation (mm):
101.5 Atmospheric Conditions

	Continuous	Beginnig shift	Mid shift	End shift
a. clear	-----	-----	-----	-----
b. fog	-----	-----	-----	-----
(x)c. cloudy	-----	(x)	-----	-----
(x)d. overcast	-----	-----	(x)	(x)

102 Average skid or forwarding distance: 200 meters

FORM 2

306.20 Ground Condition- General

Study ID: (1)
Date: 9/30/83
New (x), Revised---

	CPPA Class
306.201 Ground Strength	
a. coarse sand,gravel	1
b. medium coarse sand, sandy loams	2
c. fine sands, sandy silt, clay loam	3-4(x)
d. silt, clay, and sandy clay	4-5
e. organic	5
306.202 Ground Roughness	
a. very even	1
b. slightly uneven	2(x)
c. uneven	3
d. rough	4
e. very rough	5
306.203 Slope	
a. level 0-10%	1
b. gentle 11-20%	2
c. moderate 21-33%	3
d. steep 33-50%	4(x)
e. very steep <50%	5

306.204 Average depth of humus layer
a. <10 cm (x)b. 10-30 cm c. 30-50 cm
d. 50-100 cm e. >1 m

306.205 Slope relation to access
a. level (x)b. uphill c. downhill
d. on contour e. rolling or broken

306.206 Soil moisture
a. frozen b. dry c. fresh (x)d. wet
e. saturated f. underwater

306.207 Snow

306.207.1 Snow depth average: 0 cm

207.2 Surface
a. loose-powdery b. loose-wet c. light crust
d. moderate crust e. heavy crust

FORM 3

306.30 Working Conditions

```
                                           Study ID: (1)
                                           Date: 9/29/83
                                           New (x), Revised---
 306.31 Stump area, felling
 306.311 Slope Class    1     2     3  (x)4     5
 306.312 Footing
(x)a. firm- no sinkage or slipping
   b. soft- walking man penetrates 5 cm
   c. very soft- walking man penetrates 10 cm
   d. slippery, humus, mud, stones, moss, ice, rain
   e. obstructed, snow, mud, water
 306.313 Brush
   a. open, no obstruction to movement
   b. light, circuituous travel unobstructed
(x)c. moderate, movement impeded slightly
   d. heavy, movement difficult, some clearing required
   e. very heavy, clearing nearly always required
 306.314 Residual stand interferance
   314.1 % of trees over 10 cm left standing: 0
   314.2 Residual stems are
    (x)a. cull- can be damaged
       b. to be removed in second pass- moderate
          damage acceptable
       c. future crop trees- damage unacceptable
 306.315 Snow
   315.1  depth : 0 cm
   315.2 Surface
       a. loose, powdery
       b. loose, wet
       c. light crust
       d. moderate crust
       e. heavy crust
 306.316 walking quotient: 1.67
```

FORM 4

306.32 Stump Area- Processing

Study ID: (1)
Date: 9/29/83
New (x), Rewised---

To be filled if processing is conducted in woods independent of felling.

306.321 Slope Class 1 2 3 (x)4 5

306.322 Footing
(x)a. firm- no sinkage or slipping
b. slippery, humus, mud, stones, moss, ice, rain
c. obstructed, snow, mud, ice

306.323 Debris
a. light- no obstruction to movement- most travel on ground
(x)b. moderate- requires caution in movement but no clearing
c. heavy- most movement on slash- some clearing
d. very heavy- movement only on slash or boles or required clearing

306.324 Organization
a. random felling (x)b. directional felling
c. bunching d. piling e. other

306.325 Snow
325.1 depth: 0 cm
325.2 Surface
a. loose, powdery b, loose wet c. light crust
d. moderate crust e. heavy crust

306.328 Walking quotient: 1.67

FORM 5

306.33 Stump Area Transport Conditions

Study ID: (x)
Date: 9/30/83
New(x), revised---

To be completed only if skidder, forwarder, or other transport equipment travels directly to stump area.

306.331 Slope Class 1 2 3 (x)4 5

306.332 Ground Roughness
1. very even 2. slightly uneven (x)3. uneven
4. rough 5. very rough

306.333 Soil moisture
a. frozen b. dry c. fresh (x)d. wet
e. saturated f. standing water

306.334 Brush, debris and residual stand
a. open- no obstruction to movement
b. light- circuituous travel unobstructed
(x)c. moderate- movement slightly impeded
d. heavy- movement difficult, some clearing required
e. very heavy- clearing nearly always required

306.335 Snow

335.1 depth: 0 cm

335.2 Surface
a. loose, powdery b. loose, wet c. light crust
d. moderate crust e. heavy crust

306.336 Material Organization
a. random orientation (x)b. directional orientation
c. bunched d. tumbled e. piled f. other----

306.338 (1.67)walking and/or machine movement quotient

FORM 6

306.34 Strip Road/Skid Trail Conditions

Study ID: (1)
Date: 9/30/83
New (x), Revised---

306.340 No trail
906.341 Slope Class 1 2 3 (x)4 5

306.342 Slope relation to access (direction of loaded travel)
a. level (x)b. uphill c. downhill
d. rolling or broken

306.343 Roughness
1. very even 2. slightly uneven (x)3. uneven
4. rough 5. very rough

306.344 Origin
a. no preparation (x)b. clearing only c. clearing and humus removed d. bladed e. bladed and ditched
f. bladed, ditched and some surface applied g. other

306.345 Surface Composition
a. organic b. clay c. silt
d. fine sand/loam(x) e. coarse sand f. gravel
g. stone h. rock i. snow j. ice k. slash

306.346 Surface moisture
a. frozen b. dry (x)c. fresh d. wet
e.saturated

306.347 Surface condition
a. smooth (x). rutted c. holes and protrusions
d. corrugations e. other

306.348 Alignment
a. straight (x)b. slightly curved c. winding
d. crooked e. very crooked

FORM 7

306.35 Landing or Roadside Conditions

Study ID: (1)
Date: 9/30/83
New (x), Revised---

306.35 Landing or roadside condition

306.350 ---- No landing

306.351 Slope Class 1 2 3 (x)4 5

306.352 Ground Roughness
(x)1. very even 2. slightly uneven 3. uneven
4. rough 5. very rough

306.353 Origin
a. no preparation b. clearing only
(x)c. clearing and humus layer removed
d. bladed e. bladed and ditched
f. bladed, ditched and surfaced g. other

306.354 Surface composition
a. organic b. clay c. silt
(x)d. fine sand/loam e. coarse sand f. gravel
g. stone h.rock i. snow j. ice k. slash

306.355 Surface moisture
a. frozen b. dry (x)c. fresh d. wet
e.saturated

306.356 Management
a. excellent b. very good (x)c. good
d. poor e. very poor

FORM 8

306.36 Hauling or Transport

Study ID----------
Date -------------
New---, Revised---

306.360 No Hauling

306.361 Hauling distance by product and road type

Road Type	Product 1	2	3	4	5
	(distance KM)				
Private					
Temporary					
Permanent					
Class 3					
Class 2					
Class 1					
Public Class 5					
Class 4					
Class 3					
Class 2					
Class 1					
Urban					

306.362 Road condition by product and road type (continued)

Product

Road Type		1	2	3 (distance KM)	4	5
Private						
Temporary						
Permanent						
	Class 3					
	Class 2					
	Class 1					
Public	Class 5					
	Class 4					
	Class 3					
	Class 2					
	Class 1					
	Urban					

FORM 9

306.363 Road Limitations (continued)

Private

	Temporary	Permanent 1	Permanent 2	Permanent 3
a. Maximum Gross Vehicle Weight				
b. Maximum Axle Weight				
steering				
dual				
tandem dual				
c. Maximum Vehicle Length				
d. Maximum Vehicle Height				
e. Maximum Vehicle Width				

Public

	Temporary	Permanent 5	Permanent 4	Permanent 3	Permanent 2	Permanent 1	Permanent urban
a. Maximum Gross Vehicle Weight							
b. Maximum Axle Weight							
steering							
dual							
tandem dual							
c. Maximum Vehicle							

Length		
d. Maximum Vehicle Height		
e. Maximum Vehicle Width		

FORM 10

306.37 Working Conditions- Terminal

Study ID----------
Date--------------
New---, Revised---

306.370 No Terminal

306.371		306.372	306.373	306.374
Terminal Type	Product	Scaling Method	Unloading Method	Average Turnaround
Storage Yard				
Reloading Yard				
Processing Terminal Type				
Sawmill				
Veneer Plant				
Pulpmill				
Energy concern				
Other Type				

FORM 11

306.40 Stand Conditions

Study ID: (1)
Date: 9/30/83
New (x), Revised---

306.400 Stand Volume Units: m^3
306.401 Total volume/hectare: 104.26, bases: solid wood
306.402 Merchantable softwood volume/hectare: 0 m^3
species------,------,------,------,-----
306.403 Merchantable hardwood volume/hectare:104.26 m^3
species: Oak, Hickory, Yellow poplar
306.404 Unmerchantable volume/hectare:-----
306.404.1 Because of species:-----
306.404.2 Because of size:-----
306.404.3 Because of cull:-----
306.404.4 Other:-----
306.405 Stand Density- trees/hectare
306.405.1 Total trees/hectare (> --- cm. DBH):-----
306.405.2 Merchantable softwood trees/hectare:-----
306.405.3 Merchantable hardwood trees/hectare:-----
306.405.4 Unmerchantable trees/hectare:-----
306.405.5 Large saplings/hectare (2-10 cm DBH):-----
306.405.6 Small saplings/hectare (0.5-2 cm DBH):-----
306.406 Stand height
306.406.1 Average height dominants and codominantes: 25 m.
306.406.2 Average height suppressed: 6 m.
306.406.3 Average height large saplings: 5 m.
306.406.4 Average height small saplings: 1-2 m.
306.407 Stand Origin
(x)a. natral b. direct seeded c. planted
d. natural w/selection e. seed tree
f. shelterwood g. coppice h. other------
306.408 Stand history
a. fire b. wind c. ice d.insect
e. disease f. other------
306.408.2 Management activities and date
a. sanitation cut:--- b. precommercial thinning:---
c. commercial thinnings:--- d. selection harvest:---
e. prescribed burn:--- f. chemical release:---
g. other:---

FORM 12

306.42 Check Plots

Study ID-----------
Date---------------
New---, Revised----

306.421 Plot type

a. Variable, basal area factor__________
b. Fixed-circular, radius______M
c. Fixed-rectangular, radius______Meters x ______Meters
d. Other

306.422 Tree Characteristics

Species	DBH	Comments
Plot 1		
Plot 2		

Plot 3		

FORM 13

306.43 Volume Table Development- Volumetric

Study ID-----------
Date---------------
New---, Revised----

306.431 Trees less than 10m Total height

	tree #					
	Species					
	Butt					
	DBH					
	1m					
	2m					
	3m					
Diameter (OB)-cm	4m					
or Weight (Kg)	5m					
	6m					
	7m					
	8m					
	9m					
	10m					

FORM 14

306.43 Volume Table Development- Volumetric

Study ID-----------
Date---------------
New---, Revised----

306.432 Trees 10m -- 20m Total height

	tree #						
	Species						
	Butt						
	DBH						
	2m						
	4m						
	6m						
	8m						
Diameter (OB)-cm	10m						
or Weight (Kg)	12m						
	14m						
	16m						
	18m						
	20m						

FORM 15

306.43 Volume Table Development- Volumetric

Study ID-----------
Date---------------
New---, Revised----

306.433 Trees 20m -- 30m Total height

	tree #					
	Species					
Diameter (OB)-cm or Weight (Kg)	Butt					
	DBH					
	3m					
	6m					
	9m					
	12m					
	15m					
	18m					
	21m					
	24m					
	27m					
	30m					

FORM 16

306.440 Forest Model- General

Study ID: (1)
Date: 9/30/83
New (x), Revised---

306.440.1 Forest Model Number: (1)

306.440.2 Crew Members: Dave Paduda, Hooshang Sobhany

306.440.3 Azimuth of Assumed North: N 16. E

306.440.4 Species Codes Used:

Code	Species
1	Yellow Poplar
2	Hickory
3	Locust
4	White oak
5	Red oak
6	Dogwood

306.440.5 Additional Tree Form Codes used:

Code	Species
7	Black oak
----	-------
----	-------
----	-------
----	-------
----	-------

comments:

<u>In addition complete form 306.20 describing only the ground conditions only for the Forest Model</u>.

FORM 17

306.451 Residual Stand Damage

Study ID-----------
Date---------------

Timber

Trees Left Standing

Trees Number	Potential End Use	No Damage	Damaged- Type

FORM 18

306.452 Residual Stand Damage

Study ID---------
Date-------------

Site and Soils

Legend

Symbol	Damage Type
______________	________________________
______________	________________________
______________	________________________
______________	________________________

FORM 19

306.51 Harvesting Strategy

Study ID---------
Date-------------

306.511 Tract Layout:

306.512 Sequence of cut-----------------------

306.513 Scheduling of activities

Function	Interval (time-days-weeks-months)
1______________	1-2____________________________
2______________	2-3____________________________
3______________	3-4____________________________
4______________	4-5____________________________

5________________ 5-6________________

6________________ 6-7________________

7________________

306.514 Site Inventories

Unprocessed - Stump area	________________	m^3
Processed - Stump area	________________	m^3
Unprocessed - Strip road	________________	m^3
Processed - Strip road	________________	m^3
Unprocessed - Landing	________________	m^3
Processed - Landing	________________	m^3
Roadside as Yard	________________	m^3

306.515 Special considerations influencing strategy and inventories

____

____

____

306.516 Date of completion________________

306.517 Follow up activities:

Activity	Date
________________________________	__________
________________________________	__________
________________________________	__________

FORM 20

306.52 Harvesting History

Study ID-----------
Date---------------

306.521 Access

a. Date access road completed________________
b. Date landing completed_______________

306.522 Volume harvested prior to study
a. Volume removed from site______________m^3
b. Processed and stored at roadside___________m^3
c. Volume stored on landing or at roadside awaiting processing_____________m^3
d. Processed and stored on strip roads_________m^3
e. Volume stored on strip roads awaiting processing______________m^3
f. Volume processed and stored in stump area_____m^3
g. Volume stored in stump area awaiting processing______________m^3

306.524 Preparations for harvest
a. Boundry marking
b. Pre logging-volume removed____________m^3
c. Marking take trees
d. Marking leave trees
e. Marking corridors
f. Other_________________

306.525 Previous harvesting activity ______year

Type of cut______________

FORM 21

312.00 Crew Organization and Safety

STUDY ID: (1)
DATE: 9/30/83
New (x), Revised________

312.001 Business Type: circle the term which most closely describes the business type.
(x)a. A privately owned business, holding title to all equipment, hiring labor, performing all harvesting and hauling functions.
b. A privately owned contractorship, subcontrating portions of the operation
c. A subcontractor, performing only a limited set of harvesting and hauling functions for a primary contractor or firm.
d. A landowner or agent of the landowner performing harvesting tasks on a seasonal basis.
e. A company operation, owned and administered by a wood using firm.
f. A company operation, owned and administered by a logging equipment manufacturer.
g. Other: Describe________________________________

312.002 Crew type- Circle the phrase which most closely describes the operation.
(x)a. An established production crew
b. An evolving production crew
c. A recently formed production crew
d. An established research crew
e. A newly formed research crew
f. A specially formed test or trial crew
g. Other: Describe________________________________

312.003 Supervision
a. Owner serves a full time supervisor
(x)b. Owner acts as a working supervisor, dividing time between supervision and production related work.
c. Owner acts as a mechanic/supervisor, dividing efforts between supervision and equipment maintenance
d. A full time foreman is present
e. A working foreman
f. A mechanic/foreman
g. Part time foreman

h. Part time mechanic/foreman
i. A crew member has supervision as a secondary responsibility.
j. Only planning and coordination required

312.004 Clothing and personal equipment
312.004.1 Protective clothing and equipment
(x) Provided by owner, ____Purchased by crew member

312.004.2 Protective clothing and equipment required

a. (x)Hard toed boots
b. (x)Hard hats
c. (x)Ear protection
d. (x)Eye protection
e. (x)Gloves (x)standard ____specially designed
f.____Chainsaw chaps/pants
g.____Cainsaw resistant shirts
h.____Chainsaw resistant shoes
i.____Chainsaw resistant gloves
j.____Other: Describe______________________________

312.005 First aid and emegency medical care
a._____Each machine equipped with a primary first aid kit
b._____A first aid kit capable of treating major accidents available at a central location
c._____At least one crew member has had comprehensive first aid training
d. (x)Other first aid/emergency medical consideration. Describe: basib first aid kit was available at camp near the landing.

312.006 Safety training/enforcement
a._____A regular part of the operation
b._____An awareness provided with consistent enforcement
c. (x)An awareness provided but little enforcement
d._____Casual attention only

FORM 22

312.10 Employee Description

STUDY ID______________
DATE______________
New____, Revised____

312.100 Employee Number				
312.101 Employee Name				
312.102 Age (years)				
312.103 Harvesting Experience (years)				
312.104 Time with crew (months)				
312.105 Pay method				
312.106 Pay rate				
312.107 Fringe Benefits				
312.108 Special Training				
312.109 Handicaps or Other				

FORM 23

312.11 Tasks and Skills

STUDY ID____________
DATE______________
New____, Revised____

312.110 Employee Number				
312.111 Employee Name				
312.112 Primary Task				
Description				
312.113 Skill level				
312.114 Secondary Task				
Description				
312.115 Skill level				
312.116 Teritiary Task				
Description				
312.117 Skill level				

FORM 24

312.12 Periodic Pay and Production

STUDY ID____________
DATE________________
New____, Revised____

312.121 Period from:__________ to__________

312.122 Employee Number					
312.123 Regular Hour of Work					
312.124 Premium Hours Worked					
312.125 Production					
	Type				
	Amount				
312.126 Comments					

FORM 25

312.13 Accident or Illness Report

STUDY ID_______________
DATE_______________
New_____, Revised_______

312.130 Employee number_____ Date__________
312.131 No lost time accident=1
Lost time accident =2
Illness =3
(complete 312.132 and go to 312.138)
312.132 Time of occurance or manifestation_________
312.133 Body part(s) affected______________
312.134 Description of severity______________
____
____
312.135 Description of cause______________
____
312.136 Corrective action______________
____
312.137 Prognosis______________
____
312.138 Symptoms______________
____

FORM 26

312.14 Resignation/Termination Report

STUDY ID____________________
DATE________________________
New_____, Revised__________

312.140 Employee Name - Number__________________________

____

312.141 Action: Resignation Termination

312.142 Effective Date__________

312.143 Reason____

____

____

____

____

312.144 Comments:

FORM 27

312.20 System Description

STUDY ID: (1)
DATE: 9/30/83
New (x), Revised________

312.201 System Type
a. An established production system in normal environment
b. An established production system in a new environment
(x)c. An established system incorporating new equipment
d. An experimental system testing application concept
e. An experimental system testing machinery concepts
f. An experimental system testing specific machinery

312.202 System longevity:__________years

312.203 System ownership:__________

312.204 Production history:
Average weekly productivity__________________
Last month__________________
Last quarter__________________
Last year__________________

312.205 Operating History:

Average weekly productivity__________________

Last month__________________
Last quarter__________________
Last year__________________

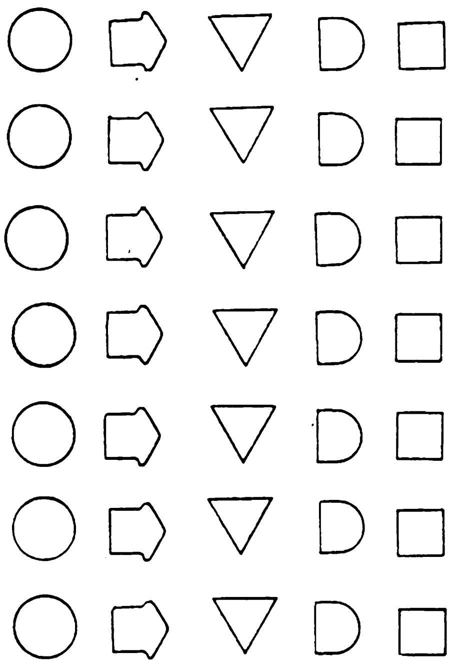
312.206 Average Crew Size: Number of productive and support personnel

Average weekly productivity__________________
Last month__________________
Last quarter__________________
Last year__________________

FORM 28

312.21 Material Flow

STUDY ID ______________
DATE ______________
Observer ______________

312.211 Activities	312.212 Function Description	312.213 Work Unit
		

FORM 29

312.22 Machine Conditions and Dimensions

STUDY ID: (1)
DATE: 9/30/83
New (x), Revised________

312.221.0 Machine Make: FMCand Model Number:FT-180
221.1 Machine Identification Number:(1)
221.2 The Machine can best be described as:
(x)A) A first prototype
B) A second prototype
C) A preproduction machine
D) A production machine

312.222 Machine Condition
222.1 Machine age: (8) Months
222.2 Engine hours______
222.3 Condition
(x)A) Excellent B) Very good C) Good
D) Fair E) Poor

312.223 Price: $135000
223.1 Manufacturer's list price: $135000
223.2 Percent Depreciated:__________

312.224 Machine Dimensions
224.1 Length
224.10 (Meters) Overall Length: 5.69
224.11 (Meters) Base Machine only: 4.674
224.12 (Meters) Wheel Base or Track Length: 2.286

224.2 Width
224.20 (Meters) Overall Operating Width: 2.13
224.21 (Meters) Width of Base Machine only: 2.13
224.22 (Meters) Center to Center, Tires or Track: 1.73
224.23 (Meters) Outside to Outside, Tires or Track: 2.13

224.3 Height
224.30 (Meters) Overall Operating height: 2.794
224.31 (Meters) Total Height for Transport: 2.794
224.32 (Meters) Height, Base Machine only: 2.794

224.4 Weight

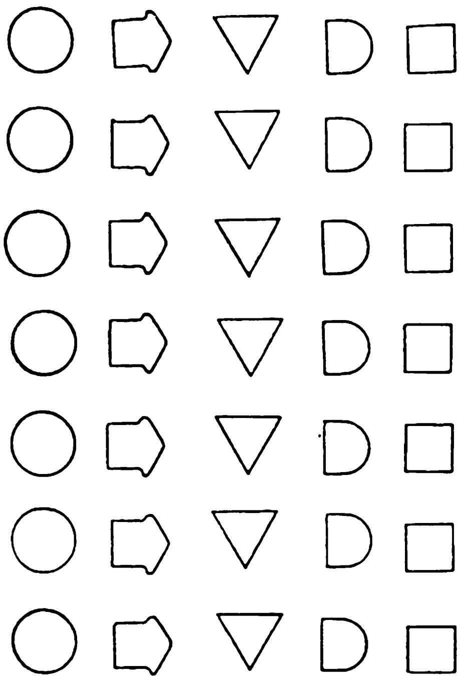
224.40 (Kgs) Curb Weight, Machine and
Attachments: 9800
224.41 (Kgs) Total Weight , Machine and
Design Load: 18000
224.42 (Kgs) Curb Weight, Base Machine only: 9800

224.5 Weight Distribution
224.50 (%) Empty Weight Distribution on front
tires or track
224.51 (%) Empty Weight Distribution on rear
tire or track
224.52 (%) Loaded Weight Distribution on front
tire or track
224.53 (%) Loaded Weight Distribution on rear
tire or track

FORM 30

312.23 Machine or Task Description

STUDY ID________________
DATE____________________
Observer ________________
Machine ID (or task)_____

312.231 Activities	312.232 Function Description	312.233 Work Unit
	____________ ____________ ____________ ____________ ____________ ____________ ____________ ____________	____________ ____________ ____________ ____________ ____________ ____________ ____________ ____________

FORM 31

352.0 Periodic System Production

Study ID____________
Date________________
New____, Revised_____

Period: From________ to________

352.0 Periodic System Production

Product	Volume transferred or produced	Unit	Market
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			

FORM 32

352.1 Periodic Expense Report (Individual Machine)

Study ID____________
Date________________

352.11 Consumable supplies

352.111 Machine ID______

352.112 Period from date_______ shift to date_______ shift

352.113	352.114	352.115	352.116		352.117	352.119
			Oil (liters)			
Shift	Service Interval	Fuel (liters)	engine	Drive train Hydraulic	Lubricant KG	other Specify
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						

15						
16						
17						
18						
19						
20						
21						

FORM 33

352.1 Periodic Expense Report (Individual Machine)

Study ID______________
Date__________________

352.12 Service materials

352.111 Machine ID______

352.122 shift	352.123 Service interval	352.124 Supplies used	352.125 Parts and materials used

FORM 34

352.2 Detailed Recorder Analysis

Study ID____________
Date________________

352.2 Datailed Recorder Analysis

Machine No.________ Operator(s)________________________

Start Time_________ Stop Time_________

Time (minutes)

Operating	Productive									
	Non Productive									
	Other									
Idle	Mechanical	Service								
		Repair								
		Modification								
	Non Mechnical	Personnel								
		Operator Lost								
		Inventory								
		Weather								
		Other								

FORM 35

352.20 Shift Recorder Analysis

Study ID: (1)
Date: 9/29/83

352.201 Date: 9/29/83 352.202 Shift: first
352.203 Machine: FMC 352.204 Operator: S.B. Armentrout
352.210 Period
352.211 Start time: 13:00 353.213 Start time:______
352.212 Stop time: 15:26 352.214 Stop time:_______
352.220 Operating time: 2:26
352.221 Productive: 1:44:40 Describe: Skidding
352.222 Non Productive: 0:41:20 Describe:waiting at the landing
352.223 Other

______________ ____________________
______________ ____________________

253.230 Idle or down time
253.231 Mechanical
352.231.1 Service: Active_______ Waiting_________
352.231.2 Repair: Active_______ Waiting_________
352.231.3 Modification__________ Describe________
352.231.4 Other_________________ ________

352.232 Non Mechanical
352.232.1 Personnel_____________
352.232.2 Operator Lost_________
352.232.3 Inventory_____________
352.232.4 Weather_______________
352.232.5 No work_______________
352.232.6 Moving________________
352.232.7 Other__________ Describe____________

352.233 Comments: A better landing management would improve the productivity time of the FMC.

FORM 36

352.3 Cycle Timing

Study ID: 1
Date: 10/4/83
Machine No. 1 (FMC) Operator(s): S. B. Armentrout
Clock Time: Start 8:30 Stop 11:23

Cycle			Independent Variables				Comment
No.	Time Start	Time Stop	meter dist. 1	slope % 2	# of logs 3	DBH cm 4	minutes Delay
1	8:30	8:47	145	44	3	37	7.65
2	8:47	8:56	133	44	3	29	1.43
3	8:56	9:06	130	43	4	34	1.55
4	9:06	9:26	130	43	3	29	7.70
5	9:26	9:35	126	43	3	29	1.05
6	9:35	9:44	126	43	2	35	1.05
7	9:44	9:53	122	43	3	36	1.67
8	9:53	10:06	122	43	2	33	5.90
9	10:06	10:15	122	43	4	39	0.00
10	10:15	10:30	119	43	1	58	2.00
11	10:30	10:42	119	43	3	25	3.99
12	10:42	10:51	116	43	3	33	0.00
13	10:51	11:03	116	43	2	19	2.40
14	11:03	11:12	114	43	1	66	3.45
15	11:12	11:23	114	44	5	32	0.00

FORM 37

352.41a Work Sampling

Study ID: 1
Date: 10/6/83
Observer: H. Sobhany

Sheet # 01

Work Sampling or Ratio Delay method was employed and all activities involved in the operation were recorded. The time for observation was selected randomly throughout the study.

Time Observed	Man or Machine	Work (1) Idle (0)	Activity/Reason
7:51	:Chainsaw oper. 1	0	Rest
	Chainsaw oper. 2	1	Felling
	Chaser 1	0	Waiting
	Chaser 2	1	Choker Setting
	Bucker 1	1	Bucking
	Bucker 2	1	Bucking
	FMC	1	Travel empty
	Loader	1	Loading
	Cat 518	1	Travel empty
	Truck 1	1	Loading
	Truck 2	0	Waiting
	Truck 3	0	Waiting
	Truck 4	0	Waiting
	truck 5	0	Waiting
8:13	:Chainsaw oper. 1	0	Rest

	Chainsaw oper. 2	1	Felling
	Chaser 1	0	Wait
	Chaser 2	1	Loading
	Bucker 1	1	Measuring
	Bucker 2	1	Bucking
	FMC	1	Unhooking
	Cat 518	1	Travel loaded
	Truck 1	1	Loading
	Truck 2	0	Waiting
	Truck 3	0	Waiting
	Truck 4	0	Waiting
	Truck 5	0	Waiting

FORM 38

Elemental Time Study

Study ID: 1

Date: 10/4/83

Machine or work unit: FMC

Travel Empty= 1, Hook= 2, Winch= 3
Travel Loaded= 4, Unhook= 5, Delay= 6
(Sample)

reference	Elemental						Comments
	1	2	3	4	5	6	
	2.60	1.45	0.73	5.43	4.89	18.92	
	2.38	1.74	0.50	4.46	0.97	0.00	
	2.79	1.71	0.30	8.55	1.00	0.65	
	2.78	1.92	0.50	8.52	0.68	0.00	
	1.90	1.45	1.37	8.48	0.80	0.00	
	2.15	1.60	0.47	8.88	1.05	5.55	
	2.68	2.10	0.64	10.28	1.10	0.00	
	3.12	3.08	0.60	6.82	1.08	1.00	
	2.16	4.88	0.78	5.96	0.72	0.00	
	2.52	1.20	1.43	6.45	0.40	1.50	

FORM 39

352.7 Repair Report

Study ID____________
Date________________

Machine No.__________

352.71 Nature of repair
352.711 Machine component or assembly involved_____
352.712 Repair type________________________________
352.713 Materials used_____________________________
352.714 Crew time involved_________________________
352.414.1 Operator__________________
352.414.2 Mechanic__________________
352.414.3 Other_____________________

352.72 Cause of repair
352.721 accident, abuse, wear, fatigue, other
352.722 other components affected as a result of the failure or accident:

____
____
____

352.723 Could down time have been reduced:
a. By replacement before failure
b. By maintaining larger on site parts and tool inventory
c. By better communications/scheduling of mechanic

352.73 Corrective action taken

____
____
____

352.74 Repair is considered permanent - temporary

FORM 40

352.8 Modification Report

Study ID____________
Date________________

Machine No.__________

352.8 Modification Report

352.81 Nature of modification

352.811 Machine component or assembly involved_____

352.812 Modifications made__________________________

____

____

____

352.813 Materials used______________________________

____

____

352.814 Crew time involved_________________________

352.814.1 Operator___________________

352.814.2 Mechanic___________________

352.814.3 Other______________________

352.82 Reason for modification______________________

____

____

____

FORM 41

370.01 Concept Adequacy

Study ID: (1)
Date: 10/4/83
New (x), Revised____

370.011 The product from the machine matches local system and market requirements or can be economically altered to meet those requirements: (10)

370.012 The machine matches with capital and labor requirements of the production force
- 012.1 Private land owners
- (x)012.2 Small contractors
- 012.3 Large contractors
- 012.4 Company operations
- 012.9 Other

370.013 The machine can easily fit into an existing system or machines are available or under development to provide a complete system: (10)

370.014 The operating environment for the machine will not impose any particular performance penalties. The environmental factors include: _____
- 014.1 Terrain
- 014.2 Soils
- 014.3 Climate
- 014.4 Weather
- 014.5 Species
- 014.6 Tree Size
- 014.9 Other

370.015 The training and support required to put the machine in service is within normal bounds. The considerations include: (10)
- 015.1 Training in planning
- 015.2 Supervisory training
- 015.3 Operator training
- 015.4 Mechanic training
- 015.5 Special tools and equipment

015.6 Special fuels, lubricants and fluids
015.7 Special parts inventories
015.8 Special scheduling considerations
015.9 Other

370.016 Contribution and gain of machine to the industry: ____

370.017 Utilization of the machine without extensive support and communication back-up: (10)

370.018 Flexibility to adapt effectively to changing sites, stands, and other conditions which may be encountered over its lifetime: ____

370.019 Other

FORM 42

370.02 General Design Adequacy

Study ID: (1)
Date: 10/4/83
New (x), Revised____

370.02 General Design Adequacy

370.021 Overall considerations

021.1 Machine dimensions appropriate for timber, terrain, and transport: (10)

021.2 Machine construction appropriately robust for task: (10)

021.3 The use of exotic or non standard components has been minimized: (090

021.31 Exotic or non standard parts can be easily replaced by more familiar or readily available components: (08)

021.32 Exotic or non standard parts have been sufficiently tested or have sufficient history in related fields to warrant inclusion: (10)

021.4 The machine design is built up from modules of related components:

021.41 Repair by component replacement facilitated: ____

021.411 Components can be altered or redesigned without unduly affecting machine integrity: (01)

021.412 Possibility of using alternative engines to get advantage of local service if necessary: ____

021.413 Ease of unit replacement of all major hydraulic components: ____

370.022 Power, power transmission and similar components adequate for local conditions: (10)

022.1 Components can be selected to meet needs: ____

022.2 Gear ranges adequate for local soils and terrain: (10)

370.023 Chassis and undercarriage adequate for expected application: (10)

023.1 Sufficient floatation for expected condition: (10)

023.2 Tipping angle greater than expected operating condition: ____

023.3 Steering and protection adequate for the environment and application: (08)

023.4 Tires or tracks sufficiently robust for the application: (10)

023.5 Sufficient clearance around tires and tracks allow installation of chains, service, replacement or repair: ____

370.024 <u>Cab design, location, and access adequate</u>: (10)

370.025 <u>Machine is sufficiently shielded and protected for work environment</u>: (10)

025.1 Design is "clean". Components are mutually protected. Pockets, flats and openings have been avoided: (10)

025.2 Hosing, lines, wiring and shafts enclosed or protected: (10)

025.3 Electrical system adequately protected and fused: (10)

025.4 Exhaust system designed and located to reduce fire hazards: (10)

025.5 Fire prevention and suppression consideration adequate: (03)

025.6 Good exhaust location to prevent debris accumulation: (10)

025.29 Other

370.026 <u>Hydraulic system design considerations</u>

026.1 Adequacy of hydraulic components

11 Durability: (10)

12 Reliability: (10)

13 Cold-weather: (10)

14 Oil contamination: (10)

19 Other: ____

026.2 Standard thread used for hydraulic components: ____

026.3 Adequate controls and trouble shooting considerations with regard to hydraulic system: ____

026.31 Possibility of checking pressure at each important hydraulic component: ____

026.32 Inclusion of a warning system for a low hydraulic oil level and over heating: ____

026.33 Inclusion of a temperature gauge in the hydraulic oil tank: ____

026.4 Hydraulic tank size adequate for cooling and conditioning of oil before recirculation: (10)

026.5 Drip tray arrangement for all major hydraulic components to drain the leaks outside the machine and to permit repair without oil spilling over the machine: ____

026.6 Standardization of hoses sizes and lengths: ____

026.7 Hoses and plumbing well arranged and anchored to prevent loosening and damage to fittings due to machine movement: ____

026.71 All hydraulic hoses adequately covered with heavy duty rubber: ____

026.72 Adequate protective shielding for all points of hose abrasion: (10)

026.73 Guards provided for hydraulic hoses wherever the danger of damage from terrain or trees is expected: (08)

026.74 High quality steel tubing and fitting used throughout the design: ____

370.027 <u>Steel section, built up and welded parts</u>

027.1 All welds of good workmanship and quality: (10)

027.2 Wear plates used where appropriate: ____

027.3 Sections subject to damage and repair can be easily replaced: ____

FORM 43

370.03 General Service and Repair Considerations

Study ID: (1)
Date: 10/4/83
New (x), Revised_____

370.031 Daily Service

370.031.1 Access to daily service points

031.11 Fuel: (10)
031.12 Engine oil: (10)
031.13 Coolant: (10)
031.14 Air filters: (10)
031.15 Batteries: _____
031.16 Hydraulic filter, reservoir: _____
031.19 Other: _____

370.031.2 Periodic Service

031.21 Access to lube points obvious and easy: _____
031.22 Common point lubrication used where possible: _____
031.23 Protective shields, screen, bellypans and guards easily opened: _____
031.24 Well thought out service program provided: _____
031.25 Adequate considerations of mechanic comfort and protection provided: _____
031.26 Ease of cleaning the cab: _____
031.29 Other: _____

370.031.3 Service Compatability

031.31 Special supplies-oils, lubes, and filters minimized: (10)
031.32 Special tools, instruments minimized: (10)
031.33 Comfortable position for safe routine service and maintenance performance: (10)
031.34 Routine work can be performed without unnecessary heavy lifting, stretching or other physical risks: (10)
031.35 Service can be performed without getting unnecessarily wet or dirty: (10)
031.39 Other: _____

370.031.9 Other: _____

FORM 44

370.04 General Safety and Comfort Considerations

Study ID: (1)
Date: 10/4/83
NEW (x), Revised____

370.041 Access

041.1	Ladders, steps and handholds provided where needed:	(10)
041.2	Catwalks and railings provided where needed:	(10)
041.3	Gratings, non slip surfaces provided where needed:	(10)
041.4	Doors, gates, etc., open conveniently:	____
041.9	Other:	____

370.042 Cab

042.1	Cab of ROPS FOPS type:	(10)
042.2	Operator adequately protected from foreign matter entering the cab:	(10)
042.3	Sharp angles and protrusions in cab minimized:	(10)
042.4	Presence of dust, fuel and exhaust vapors in cab minimized:	(01)
042.5	Routing of fuel, fluids, and wiring through cab held to a minimum:	(10)
042.6	Cab environment adequately controlled for climate:	(01)
042.7	Cab adequately protected from noise:	(01)
042.8	Escape hatches and routes adequate for both fire and roll over:	(10)
042.9	Other:	____

370.043 Seat, and Seat/control relationships

043.1 Seat

043.11	Seat adequately placed for operator protection and visibility:	(02)
043.12	Seat well designed and anchored:	(10)
043.13	Seat belts provided:	(10)
043.14	Seat adjustments available to accomodate normal range of operators:	(10)
043.15	Seat materials and upholstery adedquate for climate:	(10)
043.16	Arm rests and head rests provided:	(01)
043.19	Other:	____

043.2 Vibration
043.21 Design of machine is such that vibration is at its minimum and separated from cab: (02)
043.22 Seat well sprung and insulated from shock: (05)
043.29 Other: _____
043.3 Seat/control relationships
043.31 Controls well designed and grouped: (10)
043.32 Control arrangement logical and efficient: (10)
043.33 Controls grouped and coded to avoid accidental or involuntary actuation: (10)
043.34 Actuating forces within recommended limits: _____
043.35 Emergency stops and "panic" switches provided: (03)
043.36 Guages, indicator lights adequate for machine and functions: (01)
043.37 Guages, and indicator lights well located and arranged: (01)
043.38 Controls can be locked for service and protection: (10)
043.39 Other: _____

370.044 Operator visibility, lighting
044.1 Operator visibility
044.11 Field of vision adequate for operation and transport: (10)
044.12 Operator visibility adequate for protection of associated crew and equipment: (10)
044.13 Obstructions of view kept to a minimum: (10)
044.14 Glass, perspex and screening designed and located to minimize glare and obstruction: _____
044.15 Glass and screening location minimizes dust, debris and film build up: (01)
044.16 Defrosters, washers and wipers provided as necessary: (01)
044.17 Side and rear view mirrors provided if neccessary: (01)
044.19 Other: _____
044.2 Lighting
044.21 Lighting adequate for transport: (01)
044.22 Lighting adequate for night operation: (01)
044.23 Area illumination consistent with normal operating reach of the machine: (01)
044.24 Illuminance adequate for distinguishing features required for normal operation: (01)

044.25 Light distribution designed to minimize glare and "hot spots": (01)
044.26 Machine interior and exterior colors selected with night operation considered: (01)
044.27 Light fixtures and wiring well protected: (01)
044.28 Maintenance of lighting features easily performed: (01)
044.29 Other: ____

370.045 Sound
045.1 Adequate operator hearing protection: (01)
045.11 With ear protection: (x)
045.12 Without ear protection: ____
045.2 Associated crew adequately protected: (10)
045.21 With ear protection: ____
045.22 Without ear protection: (x)
045.9 Other: ____

370.046 Hazard prevention
046.1 Electrical
046.11 High quality connectors for all electrical connections: (10)
046.12 Coverage of all electrical connections to avoid short-circuiting: (10)
046.13 Labels on high voltage points and locking access to unauthorized personel: (01)
046.14 Automatic circuit breaker or adequate fusing for battery: ____
046.19 Other: ____
046.2 General
046.21 Emergency brake adequate for holding machine on steepest expected slope: (10)
046.22 Discontinuation of automatic machine functions when operator is not in the cab -"Dead Man" switch: (01)
046.23 Cleaning and servicing the machine possible without moving into hazardous locations: (10)
046.24 Hazardous areas marked with clear signs: (10)
046.29 Other: ____

370.047 Associated crew safety
047.1 Communication possible between operator and related crew: (10)
047.2 Blind spots around machine minimized: (10)
047.3 "Lock-outs" to positively disengage clutches and automatic functions when

operator is not in cab: (01)
047.4 Back up signals provided and working: (01)
047.9 Other: _____

370.048 Fire and Accident Protection
048.1 Exhaust manifold, pipe and muffler adequately protected: (10)
048.2 Fuel and oil filters located to direct spillage off machine and away from ignition sources: (10)
048.3 Proper exhaust location to prevent debris accumulation: (10)
048.4 Enough protection against trees or bolts falling into the operator's area: (10)
048.5 External emergency shutdown switch provided: _____
048.6 Good location of air intake to prevent the ignition by backfire: (10)
048.7 Proper location of fuel and hydraulic oil tanks to avoid oil discharge over the machine if heated by a fire: (10)
048.9 Other: _____

370.049 Transport considerations
049.1 Machine can be folded or easily broken down to conform to standard dimensions for transport by truck: (01)
049.2 Machine is adapted to self propelled over the road transport: (01)
049.21 Steering stable at highway speeds:
049.22 Braking power and consistency adequate for highway speeds: (01)

FORM 45

370.05 Machine Components

Study ID______________
Date__________________
New_____ Revised_____

370.05 Machine Components
0.051 Engine: Make__________ Model___________
0.051.1 __ __ Power output kilowatts
0.051.2 __ __ __ __ Recommended RPM
0.051.8 Attachments and special equipment

051.81 __ Turbocharger
051.82 __ Cooling
051.89 __ Other
0.052 Transmission: Make__________ Model__________
052.1 __ Type
a. Direct gear
b. Gear with torque converter
c. Power shift
d. Hydrostatic
e. Hydrostatic/mechanical
f. Belt
g. Chain
z. Other
052.2 Reduction Range
052.21 -- --.--: 1 Maximum
052.22 -- --.--: 1 Minimum
053 Transfer Case: Make-------- Model--------
053.1 Reduction Range
1.1 -- --.--: 1 Maximum
1.2 -- --.--: 1 Minimum
053.2 -- Reversing Capability (y=yes, n=no)
054 Final Drives: Make________ Model__________
054.1 -- Type

a) Differential - Direct	Make(s) and	Model(s)
b) Differential - Planetary	"	"
c) Hydrostatic - Planetary	"	"
d) Hydrostatic - Differential	"	"
z) Other		

054.2 Reduction Range Differential Equipped Machine only
054.21 --- ---.---: 1 Low range or single speed
054.22 --- ---.---: 1 2nd speed-if availabe
054.23 --- ---.---: 1 3rd speed-if available

054.3 Reduction Range all other final drives
054.31 --- ---.---: 1 Maximum reduction
054.32 ___ ___.___: 1 Maximum reduction
054.8 --- Limited slip or lockup ability (yes, no)

0.055 <u>Undercarriage</u>

055.1 -- Type

a) Rubber tire Straight Axle Front and rear
b) Rubber tire Straight Axle Front Bogey Axle rear
c) Rubber tire Other
d) Hard track Laying-Doze type
e) Hard track Laying-Loader type
f) Soft track Laying
z) Other

0.055.2 -- Tire or track dimension (Meters)

055.21 -- Tires only

055.211 -- Front

--- ---.--- Rim sizes
--- ---.--- Width
--- ---.--- External diameter

055.212 -- Rear (if different)

--- ---.--- rim size
--- ---.--- width
--- ---.--- external diameter

055.213 -- construction of tires

055.22 -- tracks only

055.221 --- ---.---width

055.223 -- construction of tracks

0.055.3 <u>Steering</u>

05.311 -- type

a) Automatic
b) Crab
c) Articulated
d) Clutch
e) Skid
f) Other

055.32 __ Adequacy
055.33 __ Power
055.34 __ Wear-tires or tracks 10=high, 5=normal 1=low
055.35 __ Wear-clutches and drive train

0.055.4 <u>Brakes</u>

055.41 __ Location

a) Wheel
b) Differential
c) Drive shaft
d) Transmission
e) Transfer Case
z) Other

055.42 __ Activation

a) Mechanical

b) Air
c) Hydraulic
d) Electrical
z) Other
055.43 __ Type
a) Drum
b) Disc
z) Other
055.44 __ Parking brakes
A. Drum
B. Disc
c.other
0.056 Auxiliary power
0.059 Other

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