

AN ABSTRACT OF THE THESIS OF

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A model (called MERLIN) is presented that can allow the resource manager to consider the combined effects of silvicultural treatments and their effect on expected logging production and costs. This integrated analysis takes place within the framework of personal computer software readily available to most managers. This integration is accomplished by linking an individual-tree, distance independent growth simulator with a series of production equations within a spreadsheet environment. The modularized nature of the MERLIN model will also allow different growth models or production equations to be utilized without a major software revision. The MERLIN model requires an IBM compatible PC with at least 640 kilobytes of RAM. Two floppy disk drives and a printer are also required hardware. Software necessary includes a SYMPHONY software package (version 1.0 or later) and a specially revised version of the Stand Projection System (Arney 1985).

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**LINKING A GROWTH MODEL WITH
LOGGING PRODUCTION COSTING**

by

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LINKING A GROWTH MODEL WITH LOGGING PRODUCTION COSTING

INTRODUCTION

The purpose of this study was to investigate the effect of the distribution of log sizes removed when determining logging production and costs. This approach varies from more traditional analyses where productivity is calculated based on a stand average piece-size. This was done using a computer model (MERLIN) developed for this study. MERLIN (Multiple Entry Road, Logging Investment model) allows resource managers to combine a state-of-the-art growth simulator with logging production equations. The integrated model is run completely from a personal computer. This allows quick and economical cost prediction of different management scenarios. Required inputs are available and known to most resource managers.

Until recently, logging road networks and harvesting systems were designed solely for removing wood at the current harvest in the cheapest fashion possible. Little or no thought was given to how useful a proposed road system would be for managing future stands and future entries. The problem was most apparent in the mountainous regions of the Pacific Northwest, where road systems were built to access old-growth Douglas-fir stands. Subsequent forest managers were faced with the problem of attempting to fit management plans for typically smaller second-growth stands around the

old-growth road network. The large tailholds which had been available during the first entry no longer existed, only compounding problems. Often the only solution was to build roads in between those roads designed for the old-growth harvest. The resulting road spacings were suboptimal, with a resulting higher construction cost. In addition, silvicultural considerations have tended to overshadow logging cost analysis in the decision making process.

Traditionally, forests have been managed based on the silvicultural goal to maximize growth. Forest engineering tasks such as road construction and harvest entries have often been considered as secondary tasks. The costs and timing of these engineering tasks were only considered in relation to the effect of a given harvest entry on future stand growth. The potential effects on present net worth of various engineering treatments was not typically considered.

Historically, integration and consideration of management and engineering costs and effects has tended to be strong in one discipline while being weak in the other. An illustration is the growth simulator DFSIM with economics (Curtis, Clendenen and DeMars 1981). This model does a good job of projecting tree growth, but its treatment of logging cost analysis is cursory. A data tape (tape 13) is the source of logging costs in DFSIM. Tape 13 is a dated matrix of machine costs broken down into a few broad machine size classes (i.e., small, medium, large etc.). LeDoux and Brodie

(1982) showed that in order to maximize financial yields, managers must consider logging and silvicultural techniques simultaneously. They manually linked cost functions developed from the THIN model (LeDoux and Butler 1981) with either the dynamic programming model DOPT (Brodie and Kao 1979) or the growth simulator DFIT (Bruce et al., 1977). In their study LeDoux and Brodie combined varying silvicultural and equipment treatments on specific sites. They showed that the joint returns from these varying combinations of treatments were greater than the sum of returns from each technique applied independently.

While LeDoux and Brodie's results pointed out the benefits of simultaneous consideration of logging and silvicultural techniques, the combination technique was not conducive to relatively quick and easy analysis. The models used in their analysis were mainframe computer based, making access to their model difficult. The development of an approach based on a personal computer is recommended to help alleviate this shortcoming. Gonsior (1981) developed a single entry costing model that examined yarding in an L-pattern to a landing. Gonsior's model includes a category of labor-intensive cost activities, as well as felling and hauling costs. Olsen (1985) extended Gonsior's work by developing MEHARV (Multiple Entry Harvesting Cost model). The MEHARV model examines the net present value of costs and revenues from multiple period activities. It also considers

landing construction and annual maintenance costs. MEHARV was developed as a spreadsheet template. Since spreadsheet software is now readily available to most personal computer users, MEHARV can be run in an environment available to most managers at a low cost.

While the MEHARV model considers the costs of engineering activities in detail, several silvicultural pieces of information are required for financial calculations within the model. This information, which includes the volume per acre of timber removed in a harvesting entry and indirectly includes some estimate of the piece-size distribution to be removed, is not easily predicted without growth and yield tables or a growth simulator. The MERLIN (Multiple Entry Road, Logging Investment) model was developed to help bridge the gap between accurate activity cost projection and state-of-the-art growth modeling. Given a set of logging cost equations, it was desired to interactively generate growth and yield data to enhance the accuracy of financial projections. MERLIN allows the user to link the Stand Projection System (SPS) model (Arney 1985) with a spreadsheet based activity costing environment. The financial effects of various combinations of silvicultural and logging regimes can be examined simultaneously, building upon the procedure developed by LeDoux and Brodie. The entire model is operated from within the spreadsheet environment. The model operates on a personal computer, and

is therefore an inexpensive planning tool for the resource manager. The MERLIN model might best be understood with the aid of a general flowchart and more detailed explanation of its major components. This is presented in the following section.

EXPANSION OF MERLIN COMPONENTS

The MERLIN system flowchart (Figure 1) demonstrates the model's main components and their integration. The stand projection model used is represented along the left-most branch of the flow chart. The production equations utilized are represented by the offset node located near the bottom of the chart. The spreadsheet environment is utilized for all steps in the MERLIN model except the left-most branch. Descriptions of these major components follow.

Stand Projection System

The Stand Projection System (SPS) model is the growth simulator providing silvicultural inputs to the MERLIN model. The SPS model is an individual-tree, distance-independent, stand-projection model. It has distinct advantages over other growth projection systems when integration into a detailed production costing method is being considered. Some of these advantages are outlined below.

Standard yield tables were the normal means of obtaining growth information prior to the 1970's. Simple inputs such as age, site quality (index), and average stand density supplied the user with stand average diameter, trees per acre, basal area per acre, and volume per acre. The utility of yield tables decreases as more detailed information about stand yields becomes necessary.

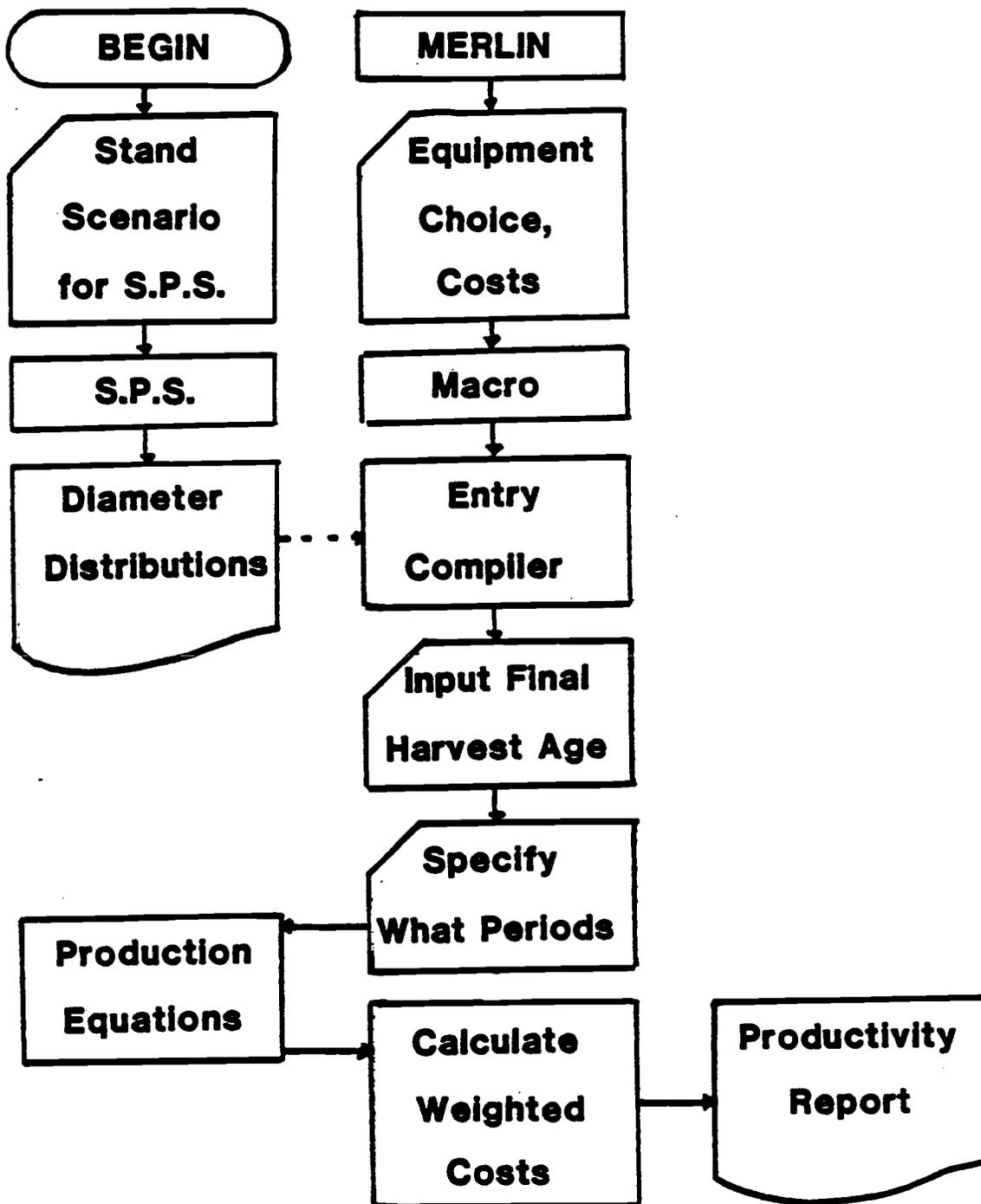


Figure 1. General flowchart of the MERLIN model

Many yield tables were based on well-stocked, naturally regenerated, pure stands of particular species. This introduces uncertainties in the validity of growth from yield tables of mixed-species or poorly stocked stands. In addition, information on the piece-size distribution to be harvested is often necessary to adequately match harvesting equipment with stand conditions to maximize the present net worth. Stand average models such as DFSIM (Curtis et al., 1981) also do not provide an adequate description of the size frequency distribution.

Individual-tree, distance-dependent models attempt to characterize both annual tree diameter and height growth, but require extensive detailed data. A stand is broken into several strata and the development of a few representative trees from each strata is simulated. Estimates of any stratum mean are obtained via this method. The stratum mean estimates are then combined into an estimate of the structure of the entire stand. While these models are useful for predicting the effects of spatial variation and can maintain a closer approximation to the structure of any given stand than can a stand average model, they require large amounts of computer time to forecast yield. Individual-tree, distance-dependent models also require voluminous input in the form of stem-mapped plots. This information is typically not available to the forest manager for many areas.

The distance-independent growth model provides for all the mixed size class, age-class, and species mixture capabilities of the distance-dependent models. Distance-independent models execute much faster than distance-dependent models on the computer and require more conventionally available tagged tree plot information. SPS is an improvement over previous distance-independent models since it efficiently projects yield reports for any requested age without introducing bias. Bias can be a consideration within other distance-independent models such as PROGNOSIS (Wykoff et al., 1982) if a user requests yield reports at intervals different than 10 years. This bias may be manifested as higher or lower projected yields, and the magnitude of the bias varies. SPS utilizes approximate 7-year growth simulation increments. If yield reports are requested for an age not a multiple of the growth simulation increment, stand report information is obtained within the model by interpolation. For this reason SPS was chosen as the growth simulator to be used with MERLIN.

SPS is a relatively easy model to run, and both forest engineers and forest managers should have a sufficient silvicultural background to simulate most Western Oregon and Western Washington stands. Information required to create an SPS run is comprised of eight distinct blocks. These blocks are:

KEYWORD	INFORMATION REQUIRED
STAND	Site index reference species, site index in feet, initial stand age, geographic region code.
NAME	Stand label or run title, comments.
MERCH	Stump height in feet, log length including trim, top diameter limit, and smallest merchantable tree.
THINNING	Minimum age to thin or minimum crown competition factor (CCF) to thin, age of CCF level, residual stand level (3 bases allowed), value of residual stand level, type of thinning, value of DBH limit for cutting, and 1st, 2nd and 3rd most preferred species to retain.
FERTILIZE	Stand age for application, rate of nitrogen application in pounds of nitrogen per acre.
TABLE	Species code, average diameter of species, top height of species, trees/acre of species or actual stand table, breast height age of species, standard deviation as a percentage of the average diameter, and stand origin.
CLUMP	Average portion of acre stocked with trees.
REPORT	Stand ages at which yield reports are requested.

The interested reader is referenced to the SPS User's Guide (Arney, 1985) for more detailed information on required user inputs.

The above supplied information is written into an input file that the user names. Control is then passed to the main SPS program, which simulates the growth of the prescribed stand. A report is generated and sent to a printer, and an abbreviated report is written to the computer disk in a temporary file. A typical SPS run report supplies information on the stand structure projected for all entries and all report ages requested. Each age report consists of a summary header, followed by a diameter class report of

pertinent stem information. A periodic annual increment and mean annual increment graph is produced after all necessary age reports are produced. Explanation of how these reports are integrated into the MERLIN structure follows in a later section of this paper.

Production Equations

The yarding equipment production equations utilized in the MERLIN model were developed by LeDoux with the use of the THIN model (LeDoux and Butler 1981). Ten production equations (LeDoux and Starnes, 1986) are available within the MERLIN model. They vary from traditional logging regression equations in that their results supply an hourly production rate rather than minutes required per turn. The equations used in MERLIN are matched to several different yarding machines and equipment configurations. Machine types included in these previously unpublished equations include a Mini Alp standing skyline, a Koller K-300 with and without a rubber-tired skidder, a Peewee system, a Skagit SJ-2 system, three West Coast yarder systems (comprised of three, four, or five chokers flown), a truck-mounted Skagit GU-10, and a Schield Bantam T-350. Variables used in these production equations include the average slope yarding distance, the volume per acre being removed, and the average log volume being harvested. Limits for the above variables include an average slope yarding distance between 50 and 950 feet, a volume per acre removed of between 355 and 7535 cubic feet

per acre, and log volumes between 6 and 18 cubic feet for prebunching and swinging equations, or 6 to 30 cubic foot log volumes for all other cases. A summary of the production equations can be found in Appendix 5.

These ten machine equations were developed by solving for logging productions in a range of average slope yarding distances and total volumes removed over a range of piece sizes. This work was accomplished through the use of the THIN model. Data sets comprised of 250 data points per machine configuration were developed. The results of these data sets were combined via regression techniques into the delay-free equations summarized in the appendix. Multiplicative adjustment factors to allow for delay are applied to the delay-free results.

The delay factors supplied with the production equations account for the following delays: personal, mechanical, resetting of chokers to free hang-ups, sorting of rigging, landing delays, repositioning of turns on the deck, moving the carriage stop, broken line(s), and lines fouled on drum sets. The delay factors provided do not include road and landing changes or initial move-in and rig-up. These are included in the landing construction cost input.

Figures 2 and 3 demonstrate the effects of the relevant variables on LeDoux's production functions. The predicted cost of removing 8, 10, and 14 cubic foot volume logs is

LOW VOLUME (1000 ft³/acre) YARDING COST

6, 10 and 14 ft³ logs removed

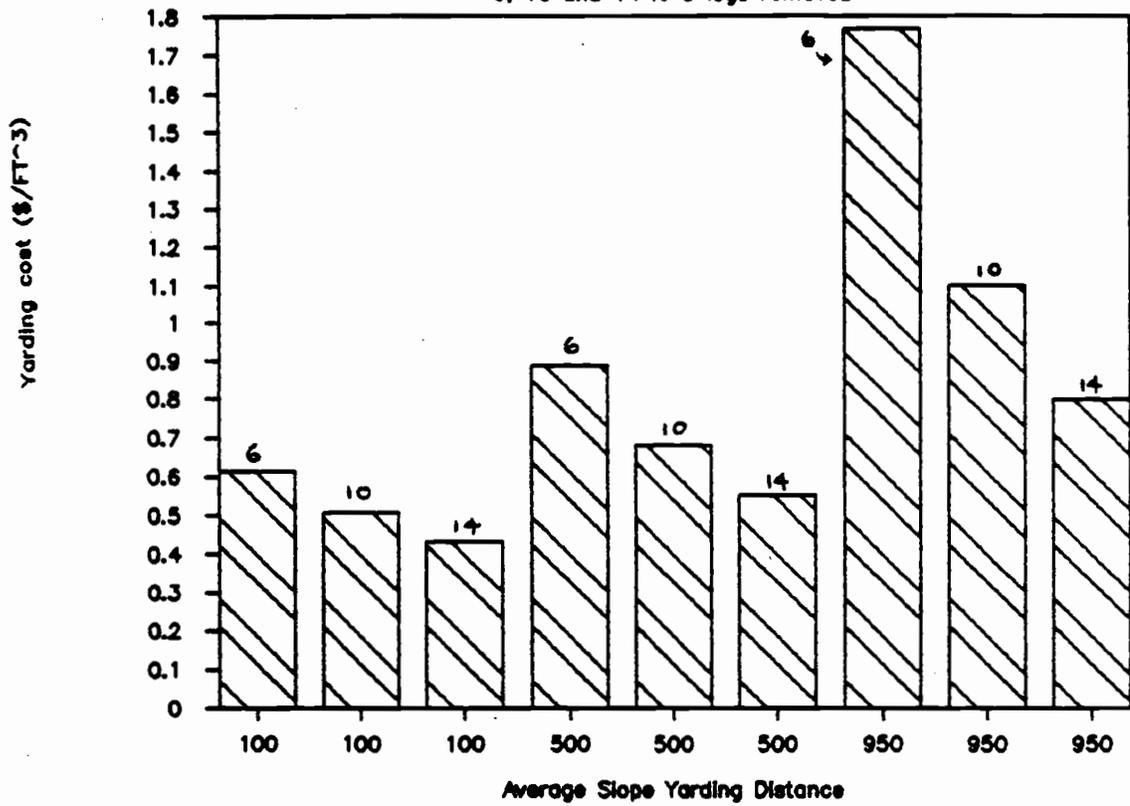


Figure 2. Low volume predicted costs

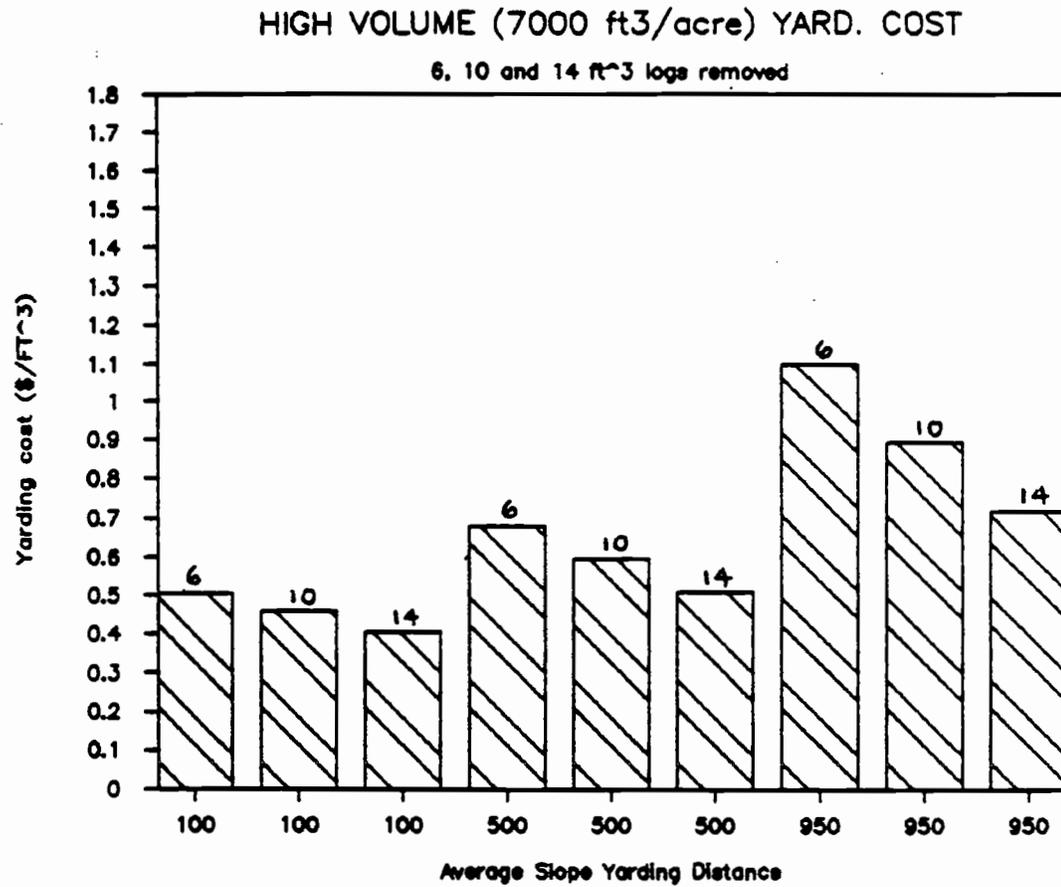


Figure 3. High volume predicted costs

graphed over a range of average slope yarding distances. The effect of total volume removed on logging costs is demonstrated via the high and low total volume examples. The production equation used to create data points in Figures 2 and 3 was for a West Coast yarder with 3 chokers, costing \$300 per hour to operate.

The Spreadsheet Environment

The production and financial analysis calculations accomplished within MERLIN are contained within the Lotus SYMPHONY software package. Spreadsheets are software packages that allow one to program "templates" that will accomplish specific calculations. A template might be pictured as a series of words and numbers written onto a blank sheet of paper. In normal hand calculations, a person might "fill in the blanks" of a calculation form and then work through all equations to arrive at an answer. Spreadsheets might be considered as the blank paper on which the calculations are written, and the template might be envisioned as the writing that comprises the calculation form. The spreadsheet/template duo is a very powerful tool for many forms of analysis, since the work area of the spreadsheet is laid out much as a ruled sheet of columnar paper. The template can then be viewed as a series of pieces

of paper... one series of "pages" being inputs and another series of "pages" being outputs. Spreadsheets can accomplish hundreds of calculations quickly with only one or two keystrokes.

The SYMPHONY spreadsheet software used in the development of the MERLIN model is also capable of being programmed to allow communication and transfer of data between the spreadsheet environment and other computer software environments. This capability is extensively used within MERLIN, allowing the user to accomplish complex data transfers with only a keystroke or two. Programmed keystrokes such as those described above are called "macros".

Entry compiler

A short BASIC program accessed from within the template reads the SPS harvesting reports stored on floppy disk. This program converts the SPS data into cubic foot units and sorts the information into a form capable of being read by the spreadsheet program. Appendix 4 contains a sample printout of this program followed by more detailed information on this subroutine.

DEVELOPMENT OF THE MERLIN MODEL

The original direction pursued in developing MERLIN involved using the stand average model DFSIM as the growth simulator to supply some of the data inputs to the MERLIN model. DFSIM's stand harvest report was then to be used in conjunction with a set of Weibull function equations to generate a piece-size distribution for each harvest. While the concept was good, the results obtained were inferior to those supplied by Arney's SPS model. Thus the SPS model was chosen to be the growth simulator supplying silvicultural information to MERLIN. The ability of SPS versions to simulate tree growth in regions other than Western Oregon and Western Washington also made the transition attractive. It should be noted that Arney's piece-size distribution projections are well linked to his data set, while the attempted integration of DFSIM with a Weibull function was not as well matched. The DFSIM-Weibull method of predicting piece-size distributions would occasionally predict piece-size distribution curves that were unrealistic. These faulty curves predicted stem diameters far removed from those normally predicted in some age classes. The data base upon which the Weibull function was developed only considered trees 45 years in age and younger. Thus diameter distributions for older stands were predicted from separate Weibull functions, leading to disjoint distribution curves. These faulty distribution projections would trigger poor

production cost estimates within the MERLIN model. The use of the SPS model and its corresponding diameter distribution predictions eliminated the difficulties with DFSIM.

The SPS model used in conjunction with the current version of MERLIN has been modified slightly to allow integration of piece-size information into the MERLIN template. A special floppy disk file summarizing the data from all reports is created by this modified SPS package. The interested reader can learn more about these revisions within Appendix 4.

The piece-size distributions reported via the SPS model are utilized to arrive at weighted average harvest production costs rather than production rates and costs based on the stand average. A harvesting cost per cubic foot is computed for each diameter class and then weighted by its volume. The harvesting cost for each diameter class is calculated using the total volume removed from all size classes in the harvest entry as one of the independent variables within the production function. The net effect is to develop a set of logging production costs, one for every diameter class removed. These costs are then combined via a weighting technique based on the actual amount of volume removed from each size class.

The author's preconceived notion that weighted average costing based on a piece-size distribution would consis-

tently yield higher calculated wood removal costs over costing based on a stand average diameter has not proven to be accurate in all instances. MERLIN runs utilizing different diameter distributions and logging production functions have produced cases where costs based on stand average conditions were lower, while other scenarios yielded higher costs for the stand average method. Whether the weighted average costing technique produces higher or lower costs appears to depend on both the stand distribution being removed and the logging production function being utilized. Net differences in the two techniques were not greater than 2% in all examples costed, implying that either technique would be adequate for the example scenarios tested.

Equations of the type first developed by Gonsior are utilized to compute other costs on a period by period basis. Appendix 6 contains a summary of these equations.

The calculations occurring within MERLIN have been hand checked for accuracy. Up to ten periods of activities, four of which may be harvests, can be computed in a single MERLIN run. The "what-if" capabilities of the SYMPHONY spreadsheet can be utilized to help the user develop management plans that minimize the present net cost of all activities affecting an area. The SYMPHONY package is capable of displaying limited portions of the spreadsheet at one time. These controlled displays are called windows.

Windows are utilized to make the MERLIN model more user friendly. Inputs are contained within three windows, and outputs are contained in separate windows. The user can move between various windows quickly via macro-assisted single keystrokes. A menu of the macros available in MERLIN can be displayed by pressing the Alt and M keys simultaneously. Short explanations of what each macro will accomplish are displayed along with the menu choices. A more detailed summary of these macro menus is located in Appendix 7.

Running MERLIN

The MERLIN model requires an IBM compatible personal computer with at least 640 Kilobytes of RAM. The current version is set up for a two floppy drive system, although the template can be restructured for hard-drive systems. A specially revised version of SPS is required. A SYMPHONY software package (version 1.0 or later) is also required. The current SPS package requires a printer for output of long form reports, although this can be circumvented.

A typical MERLIN run is accomplished by first completing an SPS run for the area of interest. This can be accomplished from within or outside of the MERLIN spreadsheet. Several floppy disk file operations will occur automatically while running SPS. The SPS input and main program files must be in the A: drive and a formatted data disk must be in place in the B: drive at the time of the

SPS run. The input editor for SPS is called IEDIT. The stand scenario desired will be input via this program.

Revising MERLIN

While MERLIN is designed to interact with the SPS model via automatic loading of harvest information from a growth simulation, a different growth model may be used. Manual loading of this data into the MERLIN template will then be required. Starting at cell Q1, the growth data should be entered as follows:

# of diameter classes removed	year in which harvest occurs	volume/acre removed	empty
diameter class (DBH)	TPA in diam. class	volume/log in diam. class	vol/tree
diameter class (DBH)	TPA in diam. class	volume/log in diam. class	vol/tree
.	.	.	.
.	.	.	.
diameter class (DBH)	TPA in diam. class	volume/log in diam. class	vol/tree

A sample of this input form may be found in Appendix 3. All volumes are measured in cubic feet, and the year in which the harvest occurs is based on the present year being year 0. For manually loaded growth data, the number of harvest entries being analyzed must be entered in cell K1.

If other logging production functions are desired, the results generated must be in cubic feet removed per hour. If inputs other than those described above are required to drive these equations, the MERLIN template will need to be revised to supply the data.

Following the completion of the SPS run, the user should make note of the years when harvest activities occur. The SYMPHONY work environment should be entered and the MERLIN template should be loaded. If SPS is entered from within MERLIN then control will be returned to MERLIN at the completion of the SPS run.

A general "how-to" flow chart has been developed for the MERLIN model (Figure 4). Following the completion of an SPS run and the return to the MERLIN environment, the user is required to enter pertinent input information into a series of input windows (examples located in Appendix 1). A summary of the required input information follows:

<u>Input window number</u>	<u>Inputs required</u>
1	<ul style="list-style-type: none"> - Year of activity being costed. - Harvest equipment choice (1 choice for each harvest entry) - Cost per hour to operate the selected equipment.
2	<ul style="list-style-type: none"> - Average slope yarding distance in feet. - Cost/mile for design & construction of the road system. - Total decimal percentage of acreage accessed by the road system.

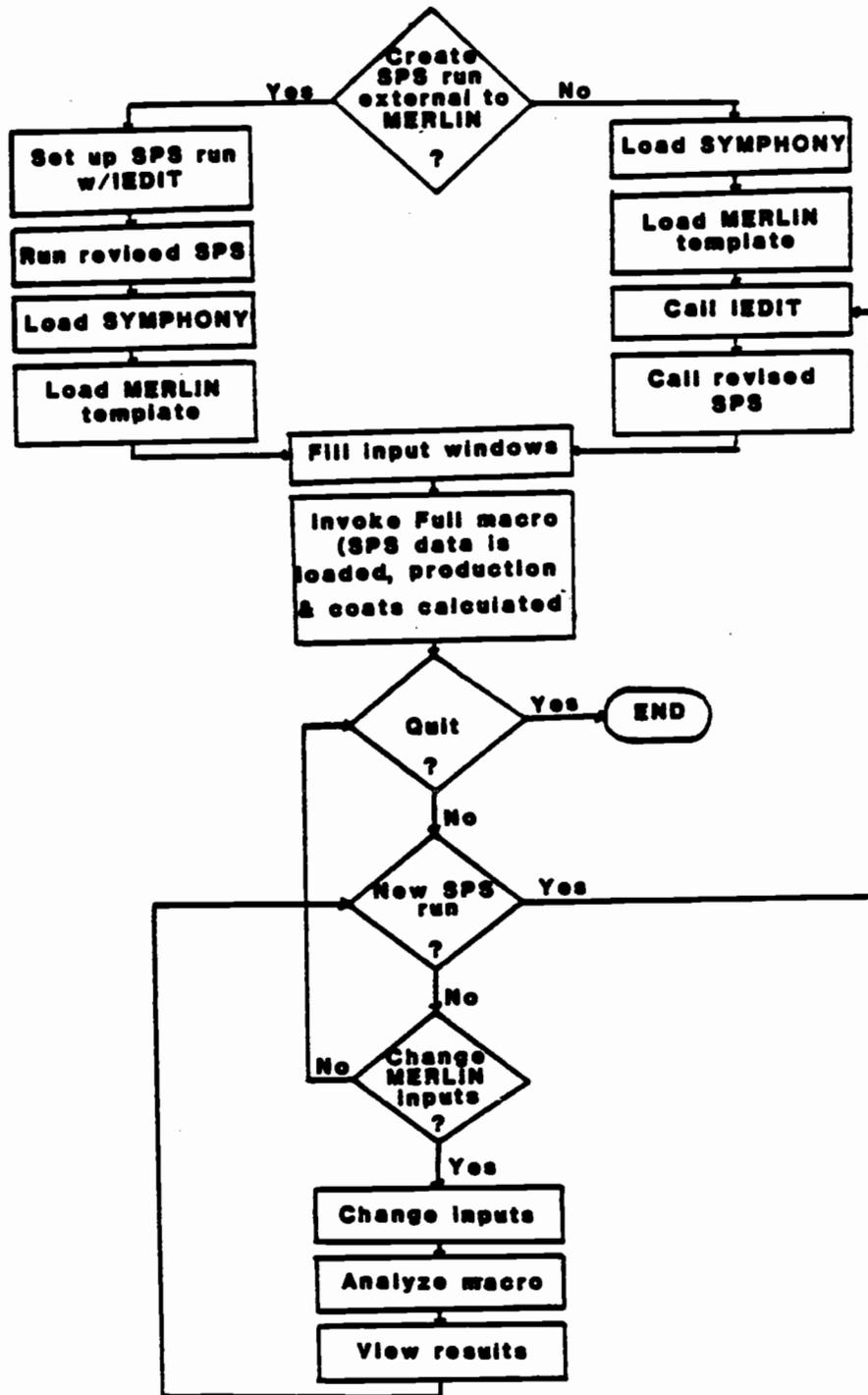


Figure 4. Operating flowchart for the MERLIN model

- One or two way yarding (Note that the built in production equations are only designed for one-way yarding.
- Daily cost of felling system.
- Felling system production rate in cubic feet/hour.
- Available hours in work day for felling & bucking.

3

- Construction cost per landing and landing change costs.
- Distance between landings along roads.
- Discount rate.
- Average maximum horizontal yarding distance or span.

After the three input windows have been filled, a macro can be instituted that will call up the SPS data and analyze the production and costs based on user inputs. Data reported in the undiscounted output summary window include the following:

- Weighted average logging cost for all diameter classes in a harvest (\$/cubic foot).
- Logging cost (\$/acre)
- Projected production (average cubic feet/day)
- Trees cut (number/acre)
- Volume removed (cubic feet/acre)
- Arithmetic mean DBH of trees cut (inches)
- Felling and bucking cost (\$/acre)
- Landing construction cost (\$/acre)
- Road construction and design cost (\$/acre)

A second output window may also be displayed which summarizes the above costs, discounted to year zero. This second output window is also accessed via a macro.

Following review of the production and cost results, two options are available to the MERLIN user. A new SPS run might be created and analyzed, or the analyst may alter any of the inputs previously entered and rerun MERLIN. It is in this follow-up analysis stage that the speed of the spreadsheet system and the ease in changing inputs can be appreciated. "What-if" analysis can also be attempted at this time. The analyst may send any window or portion of the MERLIN template to a printer at any time. This allows a permanent record of any portion of a scenario tested to be kept.

A sample problem is analyzed via MERLIN, and the results are presented in the following section. The sample input windows corresponding to the two scenarios examined are presented in Appendices 1 and 2.

A CASE STUDY ANALYSIS

In this section, a MERLIN case analysis is presented. An SPS run was created for a west-side, pure Douglas-fir stand, site index=140. Two thinnings and a final harvest were simulated via the SPS model. A thinning to a residual stand level of 150 trees per acre was requested at stand age 45. A second thinning to a residual stand level of 100 trees per acre was requested at stand age 58. Final harvest was projected to occur at stand age 150.

In the first scenario of the example problem, road and landing construction activities are forecast for entry 1. A road construction cost per mile of \$60,000 was entered. Construction costs of \$3000 per landing were also entered. A road spacing of 1600 feet is simulated in the example scenarios. Logging was assumed to occur in the second, third, and fourth entries via a West Coast yarder equipped with 3 chokers. An equipment operating cost of \$250 per hour was entered for all three entries. The reader should notice that the year of harvest activity entered in the first input window matches that described within the sample SPS run. Macros built into MERLIN will automatically match the logging cost information with the appropriate entry based on the entered year of activity.

The initial scenario described above yields the results shown in Figure 5. A second scenario was then created based on different logging equipment and operating

ENTRY SUMMARIES (UNDISCOUNTED)	ENTRY1	ENTRY2	ENTRY3	ENTRY4
>Weighted average cost per cubic ft. for all diameter classes =====>>>>		\$0.87	\$0.80	\$0.45
>Logging cost/acre (\$/acre)=====>>>>		\$2,615.92	\$1,167.02	\$3,922.12
>Avg Production/day (ft ³ /day) ==>>>		2290.59	2496.95	4454.22
>Trees per acre cut =====>>>>		160.00	45.00	90.00
>Volume per acre cut (ft ³ /acre)=>>>		2996.00	1457.00	8735.00
>Predicted avg. DBH cut (inches)=>>>		10.11	12.11	17.10
>Felling and bucking cost/acre=====>>>>	\$0.00	\$939.64	\$456.96	\$1,978.58
>Landing cost/acre (\$/acre) =====>>>>	\$326.70	\$0.00	\$0.00	\$0.00
>Road cost/acre (\$/acre) =====>>>>	\$309.92	\$0.00	\$0.00	\$0.00

ENTRY SUMMARIES (DISCOUNTED)	ENTRY1	ENTRY2	ENTRY3	ENTRY4
>Weighted average cost per cubic ft. for all diameter classes =====>>>>	\$0.00	\$0.15	\$0.08	\$0.00
>Logging cost/acre (\$/acre)=====>>>>	\$0.00	\$447.84	\$119.99	\$10.93
>Felling and bucking cost/acre=====>>>>	\$0.00	\$160.87	\$46.98	\$5.51
>Landing cost/acre (\$/acre) =====>>>>	\$326.70	\$0.00	\$0.00	\$0.00
>Road cost/acre (\$/acre) =====>>>>	\$309.92	\$0.00	\$0.00	\$0.00
>Total discounted cost/acre for all activities in the period =====>>>>	\$636.62	\$608.71	\$166.97	\$16.44
>Total discounted cost/acre for all activities in all periods =====>>>>	\$1,428.74			

Figure 5. First scenario undiscounted and discounted cost reports

costs for the two thinnings. A Koller K-300 and JD440 rubber-tired skidder were used instead of the West Coast yarder. Even though the smaller Koller yarder is projected to produce a lower average production per day for both thinning operations, the lower operating costs of the Koller yarder (\$100 per hour) allowed the weighted average cost per cubic foot of timber removed in the thinning operations to be reduced from the larger West Coast yarder's cost. The revised output results based on the Koller utilized in the thinning operations are displayed in Figure 6. No other changes in inputs were needed in the revised scenario other than machine type and operating costs for the two thinnings.

ENTRY SUMMARIES (UNDISCOUNTED)	ENTRY1	ENTRY2	ENTRY3	ENTRY4
>Weighted average cost per cubic ft. for all diameter classes =====>>>>		\$0.50	\$0.50	\$0.45
>Logging cost/acre (\$/acre)=====>>>>	\$1,508.58	\$724.15	\$3,922.12	
>Avg Production/day (ft ³ /day) ==>>>>	1588.78	1609.61	4454.22	
>Trees per acre cut =====>>>>	160.00	45.00	90.00	
>Volume per acre cut (ft ³ /acre)=>>>>	2996.00	1457.00	8735.00	
>Predicted avg. DBH cut (inches)=>>>>	10.11	12.11	17.10	
>Felling and bucking cost/acre=====>>>>	\$0.00	\$939.64	\$456.96	\$1,978.58
>Landing cost/acre (\$/acre) =====>>>>	\$326.70	\$0.00	\$0.00	\$0.00
>Road cost/acre (\$/acre) =====>>>>	\$309.92	\$0.00	\$0.00	\$0.00

ENTRY SUMMARIES (DISCOUNTED)	ENTRY1	ENTRY2	ENTRY3	ENTRY4
>Weighted average cost per cubic ft. for all diameter classes =====>>>>	\$0.00	\$0.09	\$0.05	\$0.00
>Logging cost/acre (\$/acre)=====>>>>	\$0.00	\$258.27	\$74.46	\$10.93
>Felling and bucking cost/acre=====>>>>	\$0.00	\$160.87	\$46.98	\$5.51
>Landing cost/acre (\$/acre) =====>>>>	\$326.70	\$0.00	\$0.00	\$0.00
>Road cost/acre (\$/acre) =====>>>>	\$309.92	\$0.00	\$0.00	\$0.00
>Total discounted cost/acre for all activities in the period =====>>>>	\$636.62	\$419.13	\$121.44	\$16.44
>Total discounted cost/acre for all activities in all periods =====>>>>	\$1,193.63			

Figure 6. Revised scenario undiscounted and discounted cost reports

SUMMARY AND CONCLUSIONS

A model has been developed that will allow the integrated consideration of silvicultural treatments and logging production and costs. This integration occurs within the framework of personal computer software readily available to most managers. The individual-tree, distance-independent growth model SPS (Stand Projection System) is linked with production equations developed by LeDoux (1985). This linkage occurs in a spreadsheet software environment.

The data required to successfully run MERLIN is outlined, and a general "how-to" section is presented. Methods required to use either different growth data or different logging production equations are also developed. An example run is presented, demonstrating a fixed silvicultural prescription matched with two different logging system prescriptions.

The MERLIN model calculates logging costs using a weighted average technique based on the piece-size distribution of logs removed. Comparisons of the weighted average costing technique with the more traditional stand average diameter costing technique yielded mixed results. Whether the weighted average costing technique predicts higher or lower costs depends on both the stand distribution being removed and the logging production function being utilized. Net predicted cost differences

between the two methods were not greater than 2% in all examples costed. Larger differences might be expected when logging production equations demonstrating a high sensitivity to piece-size are utilized, or when skewed piece-size distributions are removed.

The weighted average technique is an attempt at improving the accuracy of production prediction. The stand average method traditionally used is not an accurate representation of actual logging. Any given turn in most logging situations will contain a range of log sizes. The weighted average technique presented here supplies a more accurate estimate by incorporating the cost effect of various log sizes.

The treatment of piece-size frequency distribution removal costs in this thesis is still not complete. A more accurate representation of the effects of piece size on logging costs might be obtained through stochastic simulation. However, detailed time studies examining the hook and unhook phase on an individual log basis will be necessary before a more accurate model can be developed. A separate regression equation for the hook and unhook time may be necessary. The independent variables within such an equation should include at a minimum the number of logs being choked per turn, the number of choker setters, and some representation of the sizes being hooked in the turn. Perhaps an additive equation could be utilized where the

hooking time for each log is computed. A total hook time component would then be developed which could be used in a stochastic simulation environment.

MERLIN might be a useful model for resource managers who are scheduling future rotations on a given parcel of land. The growth simulator allows the manager to predict the effects of various silvicultural plans on a stand's growth. The logging cost effects of these results can be estimated with the production equations. The net result is a more informed manager who may reasonably plan future activities based on software assisted cost projections. The MERLIN model might also be useful to a forest manager who has a variety of logging systems available. The manager could predict which machine configuration would be most efficient for a given harvest. If simultaneous sales are scheduled and the manager has a finite supply of machine types available, "what-if" analysis of the sales coupled with the available machine types could aid in correct machine scheduling.

The results obtained with MERLIN are not optimized, but are simply a simulation of the scenario prescribed by the user. The MERLIN model is intended as an aid to cost prediction. It will never completely replace the manager's own common sense and experience.

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APPENDICES

Appendix 1: Scenario 1 input screens

FIRST INPUT WINDOW	ENTRY1	ENTRY2	ENTRY3	ENTRY4
> Enter the year of activity (Year 0 is the current year)=====>>>	0	45	58	150
> Enter your harvest equipment choice. Codes are: 1) Mini Alp 2) Koller K-300 w/o skidder 3) Koller K-300 w/ JD440 skidder 4) Pee wee 5) Skagit SJ-2 w/ Christy carr'ge 6) West Coast, Christy, 3 chokers 7) West Coast, Christy, 4 chokers 8) West Coast, Christy, 5 chokers 9) Skagit GU-10, truck mounted 10) Schield Bantam T-350 =====>>>		6	6	6
> Enter the cost per hour to operate the chosen harvest equip. =====>>>		250	250	250

INPUT SHEET TWO	ENTRY1	ENTRY2	ENTRY3	ENTRY4
> Enter the average slope yarding distance for the entry =====>>>	800.0	800.0	800.0	800.0
> Cost of design and construction of roads per mile (\$/mile) =====>>>	\$60,000.00	\$0.00	\$0.00	\$0.00
> Total decimal percent of acreage accessed by the road system ==>>>	1.00	1.00	1.00	1.00
> One or two way yarding (1 or 2)>>>	1	1	1	1
> Daily cost of felling system ==>>>	\$0.00	\$320.00	\$320.00	\$320.00
> Falling system production rate in volume per hour (ft ³ /hour) ==>>>	0.00	130.00	130.00	180.00
> Available hours in work day for felling and bucking =====>>>	8.00	8.00	8.00	8.00

INPUT SHEET 3	ENTRY1	ENTRY2	ENTRY3	ENTRY4
> Construction cost per landing (dollars) =====>>>	\$3,000.00	\$0.00	\$0.00	\$0.00
> Distance between landings along roads (feet). =====>>>	250.0	0.0	0.0	0.0
> Discount rate (percent) =====>>>	4.00	4.00	4.00	4.00
> Average maximum horizontal yarding distance or span (feet) =====>>>	1600	1600	1600	1600

Appendix 2: Revised scenario input screen

```

      FIRST INPUT WINDOW
      ENTRY1  ENTRY2  ENTRY3  ENTRY4
*****
> Enter the year of activity (Year
  0 is the current year)=====>>>
      0      45      58      150

> Enter your harvest equipment
  choice. Codes are:
  1) Mini Alp
  2) Koller K-300 w/o skidder
  3) Koller K-300 w/ JD440 skidder
  4) Peewee
  5) Skagit SJ-2 w/ Christy carr'ge
  6) West Coast, Christy, 3 chokers
  7) West Coast, Christy, 4 chokers
  8) West Coast, Christy, 5 chokers
  9) Skagit GU-10, truck mounted
 10) Schield Bantam T-350 =====>>>
      3      3      6

> Enter the cost per hour to operate
  the chosen harvest equip. =====>>>
      100     100     250

```

**Appendix 3: Sample form for growth simulator input
(2 entries)**

4	45	2192		2	58	933	
9	151	7.17885	11.34437	10	33	9.34838	20.27273
11	14	10.43332	19.71429	12	10	11.4655	26.4
12	6	12.08309	24.33334				
13	2	13.673	28.5				

**Appendix 4: BASIC entry compiler listing and
revisions to SPS**

```

1000 DIM ASE(20,10),DBH(20,10),TPA(20,10),BA(20,10),HT(20,10),CRBN(20,10),TOTCF(
20,10),MERC(20,10),MERS(20,10),MURL(20,10),LDBIS(20,10)
1010 DIM IASE(100),IDBN(100),ITPA(100),IBA(100),INT(100),ICRBN(100),ITOTCF(100),
INERCF(100),INERS(100),INURL(100),ILDDBIS(100),NUMDIAN(42),ASEBK(42),MNDIAN(42)
)
1020 OPEN "MURL.DAT" FOR INPUT AS #1
1030 INPUT #1,ASE
1040 CLOSE #1
1050 COUNT=1:THIN=1
1060 ASEBK(COUNT)=ASE
1070 OPEN "MURL.DAT" FOR INPUT AS #1
1080 FOR I=1 TO 100
1090 IF EOF(1) THEN GOTO 1190
1100 INPUT #1,IASE(I),IDBN(I),ITPA(I),IBA(I),INT(I),ICRBN(I),ITOTCF(I),INERCF(I)
,INERS(I),INURL(I),ILDDBIS(I)
1110 IF IASE(I)=ASEBK(COUNT) THEN GOTO 1130
1120 COUNT=COUNT+1:ASEBK(COUNT)=IASE(I)
1130 NUMDIAN(COUNT)=NUMDIAN(COUNT)+1
1140 ASE(COUNT,NUMDIAN(COUNT))=IASE(I):DBH(COUNT,NUMDIAN(COUNT))=IDBN(I):TPA(COU
NT,NUMDIAN(COUNT))=ITPA(I):BA(COUNT,NUMDIAN(COUNT))=IBA(I):HT(COUNT,NUMDIAN(COUN
T))=INT(I)
1150 CRBN(COUNT,NUMDIAN(COUNT))=ICRBN(I):TOTCF(COUNT,NUMDIAN(COUNT))=ITOTCF(I)
1160 MERC(COUNT,NUMDIAN(COUNT))=INERCF(I):MERS(COUNT,NUMDIAN(COUNT))=INERS(I)
1170 MURL(COUNT,NUMDIAN(COUNT))=INURL(I):LDBIS(COUNT,NUMDIAN(COUNT))=ILDDBIS(I)
1180 NEXT I
1190 CLOSE #1
1200 REM _____ PRINT SUMMARY _____
1210 CLS
1220 COLOR 18,0:LOCATE 3,22:PRINT "SUMMARY OF SPS REPORTS":COLOR 7,0
1230 FOR J=1 TO COUNT
1240 IF SENKASE(J,1)=0 THEN GOTO 1260
1250 IF SENKASE(J,1)=1 THEN PRINT "THINNING AT AGE";ASE(ASE(J,1)):GOSUB 1290
1260 IF SENKASE(J,1)=1 THEN PRINT "POSSIBLE FINAL HARVEST AT AGE";ASE(ASE(J,1))
1270 NEXT J
1280 PRINT:PRINT
1290 PRINT "NOTE THAT ALL THINNINGS SPECIFIED ARE SENT TO MURLIN FOR COSTING."
1300 PRINT "PLEASE SPECIFY A FINAL HARVEST AGE FROM THE LIST ABOVE WHICH OCCURS"
1310 INPUT "AFTER THE LAST SCHEDULED THINNING, ";CHICE
1320 FOR J=1 TO COUNT
1330 IF ASE(J,1)=CHICE THEN GOSUB 1290:GOTO 1380
1340 NEXT J
1350 THIN=THIN+1
1360 OPEN "B\COUNT.DTA" FOR OUTPUT AS #1
1370 WRITE #1,THIN
1380 CLOSE #1
1390 SYSTEM
1400 REM _____ WRITE FILES FOR MURLIN _____
1410 OPEN "B\DIAN"+RIGHT$(STR$(THIN,1))+".DTA" FOR OUTPUT AS #1
1420 NUMDIAN(J)=NUMDIAN(J)
1430 FOR I=1 TO NUMDIAN(J)
1440 IF MERC(J,I)/((MERS(J,I)/1000)*MURL(J,I))<6 THEN NUMDIAN(J)=NUMDIAN(J)-1
1450 NEXT I
1460 WRITE #1,NUMDIAN(J)
1470 FOR I=1 TO NUMDIAN(J)
1480 WRITE #1,DBH(J,I)
1490 NEXT I
1500 CLOSE #1
1510 OPEN "B\TPA"+RIGHT$(STR$(THIN,1))+".DTA" FOR OUTPUT AS #1
1520 WRITE #1,ASE(ASE(J,1))
1530 FOR I=1 TO NUMDIAN(J)
1540 IF MERC(J,I)/((MERS(J,I)/1000)*MURL(J,I))<6 THEN GOTO 1590
1550 WRITE #1,TPA(J,I)
1560 NEXT I
1570 CLOSE #1
1580 FOR K=1 TO NUMDIAN(J)
1590 CUTVOL(J)=MERC(J,K)+CUTVOL(J)
1600 NEXT K
1610 OPEN "B\LDBVOL"+RIGHT$(STR$(THIN,1))+".DTA" FOR OUTPUT AS #1
1620 WRITE #1,CUTVOL(J)
1630 FOR I=1 TO NUMDIAN(J)
1640 IF MERC(J,I)/((MERS(J,I)/1000)*MURL(J,I))<6 THEN GOTO 1690
1650 WRITE #1,MERC(J,I)/((MERS(J,I)/1000)*MURL(J,I))
1660 NEXT I
1670 CLOSE #1
1680 OPEN "B\TRIEVOL"+RIGHT$(STR$(THIN,1))+".DTA" FOR OUTPUT AS #1
1690 FOR I=1 TO NUMDIAN(J)
1700 IF MERC(J,I)/((MERS(J,I)/1000)*MURL(J,I))<6 THEN GOTO 1740
1710 WRITE #1,MERC(J,I)/TPA(J,I)
1720 NEXT I
1730 CLOSE #1
1740 THIN=THIN+1
1750 RETURN

```

The SPS program has been modified so that all thinning reports and requested report ages are summarized and written to a file called MERLN.DAT. The information written to this file appears as shown in the example file shown below:

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
-45	9	151.	63.6	73.9	46	1851.	1713.	6214.	38.4	6.4
-45	11	14.	9.4	79.6	50	289.	276.	1071.	24.7	7.7
-45	12	6.	5.0	80.0	50	152	146.	562.	21.5	8.3
-45	13	2.	1.9	80.2	50	59.	57.	193.	21.6	8.8
45	9	123.	53.9	77.4	48	1637.	1522.	7187.	28.7	6.5
45	10	26.	14.8	78.6	49	451.	428.	1955.	24.0	7.2
-58	10	33.	19.6	93.0	57	701.	669.	2631.	27.2	7.3
-58	12	10.	7.6	95.0	58	274.	264.	1107.	20.8	8.1
58	10	43.	25.4	93.4	57	913.	870.	3407.	27.3	7.3
58	11	40.	25.0	94.8	58	909.	870.	3169.	28.0	7.4
58	12	16.	12.2	95.0	58	439.	423.	1772.	20.8	8.1
85	13	80.	70.9	117.6	66	3118.	3030.	13600.	17.1	8.6
85	14	16.	17.7	118.7	66	773.	755.	3426.	14.1	9.6

Column definitions:

- (1) Year of entry
- (2) Diameter class (DBH)
- (3) Trees per acre
- (4) Basal area per acre
- (5) Height (feet)
- (6) Crown ratio
- (7) Total cubic feet
- (8) Merchantable cubic feet
- (9) Merchantable board feet
- (10) Number of logs per MBF
- (11) Log diameter inside bark

The columns consist of a diameter class breakdown for each thinning or other report age. The first column consists of the year of entry. Negative year reports are removal thinning reports. The positive year reports that follow after each thinning report and have the same year of entry as the thinning are the residual stand summaries. All other columns are defined in the same order as in the SPS reports.

If it is desired to link a different growth simulator with MERLIN, a file summarizing the results of runs should be produced. If the existing entry compiler is to be used, the summary should appear in the eleven column format shown above. If this is not possible or desirable, then another entry compiling system should be devised.

The only other revision to the SPS program involved changing the format of hardcopy (printed) information. The original version of SPS places a single report on each page. A more condensed reporting form is produced in the revised

SPS version. Reports are separated by two lines rather than full pages.

The BASIC entry compiler sorts the MERLN.DAT file automatically when the "full macro" option is used from within MERLIN. The compiler will automatically create harvest reports of the appropriate form for all thinning (negatively signed) reports. All other reports are summarized in chronological order, and the user is prompted to identify the final harvest age desired from this list. A caution is displayed on the screen to remind the user not to select a final harvest age occurring prior to the last thinning entry. For all harvest reports passed to MERLIN, log volumes and tree volumes are computed on a cubic foot basis. This is because the production functions utilized require cubic foot volume measurements.

Appendix 5: Production equation summary

Mini Alp, standing skyline, single	Y= +	464.05380	
and multispans with haulback, 3	-	0.29340	X1
chokers with Igland Jones single	-	453135.37054	X2
and multispans carriages.	+	0.11276	X4
(R squared = .8054, delay factor = 0.76)			
Koller K-300, standing skyline,	Y= +	549.96063	
single and multispans, gravity	-	0.38256	X1
outhead, 3 chokers, Koller SKA-1	-	412304.72884	X2
carriage without skidder.	+	0.19825	X4
(R squared = .8369, delay factor = 0.79)			
Koller K-300, standing skyline,	Y= +	615.53229	
single and multispans, gravity	-	0.45680	X1
outhead, 3 chokers, Koller SKA-1	-	449357.00156	X2
carriage, with John Deere 440-C	+	0.22712	X4
choker skidder swing away from			
Koller landing.			
(R squared = .8382, delay factor = 0.78)			
Peewee, running skyline, singlespan,	Y= +	591.95611	
3 chokers.	-	0.40840	X1
	-	621828.29021	X2
	+	0.18432	X4
(R squared = .8136, delay factor = 0.83)			
Skagit SJ-2, live skyline singlespan	Y= +	484.74971	
gravity outhead, 3 chokers, Christy	-	0.20051	X1
carriage.	-	493857.91292	X2
	+	0.10072	X4
(R squared = .6746, delay factor = 0.79)			
West Coast, standing skyline, single-	Y= +	616.65800	
span, haulback, 3 chokers, West	-	0.37505	X1
Coast carriage.	-	728220.13805	X2
	+	0.85110	X4
(R squared = .8859, delay factor = 0.78)			
West Coast, standing skyline, single-	Y= +	803.70136	
span, haulback, 4 chokers, West	-	0.39039	X1
Coast carriage.	-	177728.75982	X3
	+	0.79953	X4
(R squared = .8546, delay factor = 0.78)			
West Coast, standing skyline, single-	Y= +	893.69114	
span, haulback, 5 chokers, West	-	0.38286	X1
Coast carriage.	-	215729.34049	X3
	+	0.72506	X4
(R squared = .8298, delay factor = 0.78)			
Prebunching with truck-mounted	Y= +	801.80940	
Skagit GU-10, block rigged	-	0.77889	X1

**Appendix 6: Cost equation summary. Adapted from
Gonsior (1981)**

$$RC = K_R * C_R / S$$

where RC = per acre road costs (dollars/acre)
 $K_R = (1 / (0.121 * K_A * K_S))$
 K_R = coefficient reflecting the acres served by the roads and over which road costs are distributed (feet-mile/acre)
 K_A = fraction of the acreage accessed by the road system
 K_S = coefficient reflecting whether the yarding system can yard in one (coefficient=1) or both directions (coefficient=2)
 C_R = cost for design, construction and maintenance of roads (dollars/mile)
 S = average maximum yarding distance or span (feet)

$$FC = [(C_f * V) / (P_f * T_f)] * (1 / (1 - K_f * S))$$

where FC = per acre felling costs (dollars/acre)
 C_f = daily cost for the felling system (dollars/day)
 V = per acre volume of merchantable timber to be extracted (volume/acre)
 P_f = felling system production rate (volume/hour)
 T_f = available hours in the work day for the felling system (hours)
 $K_f = K_S / (2 * T_f * V_w)$
 K_f = a coefficient reflecting walking speed between roadside and work site, length of workday, and type of yarding system
 V_w = average walking speed (feet/hr)
 S = as defined above

$$LC = LCC / ((K_S * S * LSP) / 43560)$$

where LC = per acre landing costs (dollars/acre)
LCC = landing construction cost (dollars/landing)
ASYD = average slope yarding distance (feet)
LSP = distance between landings along roads (feet)

Appendix 7: Explanation of macro menu choices

Summarized below are the macro commands available to the MERLIN user. The first line will be the highlightable menu choice. The line below will show the short prompt displayed with each respective menu choice. The third line of each set will be a slightly longer explanation of what the macro will accomplish.

1

View input screen 1

Result: The first input window will be displayed on the screen. The left-hand window will contain text describing the required inputs. The right-hand window is the work space where inputs are entered. All input windows follow this format.

2

View input screen 2

Result: The second input window will be displayed on the screen along with it's directions.

3

View input screen 3

Result: The third input window will be displayed on the screen along with it's directions.

Output

View first output screen

Result: The undiscounted cost summary screen will be displayed. Text describing the results will appear in the left-hand window, while the numeric results will appear in the right-hand window.

Second out

View second outputs

Result: The discounted cost summary screen will be displayed. Text describing the results will appear in the left-hand window, while the numeric results will appear in the right-hand window.

Full macro

Read data from an SPS run (data in drive A:) and determine costs

Result: MERLIN will first transfer control to the entry compiler. This subroutine will write a summary file of each specified thinning in a form which MERLIN can interpret. The user is prompted to supply a final harvest age from a list of report ages. The requested final harvest report will also be written to a file readable by MERLIN. These summary files are then loaded into the MERLIN template. Weighted-average costs are calculated based on the contents of input windows. The macro menu will be displayed at the conclusion of this macro.

Analyze

Analyze diameter information currently in MERLIN

Result: Weighted-average costs for previously loaded diameter information will be calculated. This macro executes faster than the full macro, and is useful when examining the effects of changes in input windows.

Next menu

Display further MERLIN menu options

Result: The second set of macro choices will be displayed.

Graph

Graph of avg. \$/ft³ by period

Result: A graph of the undiscounted weighted-average cost per cubic foot is displayed for every harvest entry. The machine type specified for each entry is identified by number below the X-axis.

Call diameters

Call up diameter distribution(s) into MERLIN

Result: The harvest entry summary file created by the entry compiler is loaded into the MERLIN template. This macro varies from the "Full macro" in that it does not translate the SPS data file.

Input SPS

Transfer to SPS input editor

Result: Control is passed to IEDIT, the SPS input editor. The user will supply the required input to operate this program. When the input editing phase is complete, control will be transferred back to MERLIN.

Run SPS

Run current created SPS input file

Result: Control is passed to the SPS program. The user supplies a previously created input file name (created with IEDIT). SPS will run, automatically creating a data file which can later be interpreted by the entry compiler. Control will be transferred back to MERLIN at the completion of the run.

Previous menu

Return to previous menu choices

Result: The first eight macro menu choices will be displayed for the user.