THE NEED TO IMPROVE MODELS FOR INDIVIDUAL TREE MORTALITY [1]

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ABSTRACT.--The primary source of variability in projections made with a widely used single tree growth and yield simulation model employed for modelling central hardwoods was shown to be due to the individual tree mortality model. It is suggested that the most efficient way to improve the predictive ability of the overall simulation model is to direct future research towards improving the individual tree mortality models through additional data collection and model restructuring.

INTRODUCTION

Stand and Tree Evaluation Modeling System (Belcher et al. 1982), STEMS, is a single tree growth projection system that was developed by the USDA Forest Service to evaluate a wide variety of forest types in the Central States. A total of 3000 plots with 60000 trees were used to calibrate the Central States Version of the STEMS model. STEMS has primarily been used to evaluate management and silvicultural alternatives and for updating forest survey plots. The component models of STEMS are not strictly empirical, but are something in between empirical and mechanistic. The structure of the models are based on the calibration data, as well as the geometric and mechanistic properties that can be expected as a result of a long history of growth and yield research.

Gertner (1987 and 1988) used an error propagation method as a computationally efficient alternative to Monte Carlo methods to obtain estimates of precision of predictions made with a modified version of STEMS. Precision estimates for the STEMS model were desired to gauge the reliability and precision of predictions, to calculate confidence intervals, to statistically test hypotheses when experiments are performed with the model, and to weight projections used as an auxiliary source of information in combination with on-the-ground sample estimates.

Another use of the error propagation technique is for aiding in the development of future strategies for improving, in a systematic fashion, simulation models such as STEMS. Briefly described here is the method for doing this and suggestions for improving the STEMS model.

ERROR BUDGET

The error propagation method provides a direct method for calculating the variance of predictions. For each function in the growth model, an approximation is used to approximate the variance of prediction made with the function when there is random error in the input of the function. By approximating the variance for each function, the random errors that pass from one function to another can be approximated and accounted for (Figure 1). With an iterative model such as a multi-year projection system, the initial errors entered into the functions of the model might be due to errors in the state variables. After the first iteration, the errors will be due to errors in predictions from past iterations. With each additional iteration, the variance will increase as errors propagate through the system. The final variance of the prediction for the overall system will be due to the accumulation of all the errors.

With the error propagation method, an error budget can be easily generated. An error budget shows the effects of individual errors and groups of errors on the accuracy of simulation projections. It can be considered to be a catalog of the contributions of the different error sources to the overall accuracy of the system. Some specific types of errors that might be considered when developing the error budget for a model are the following (Figure 1):

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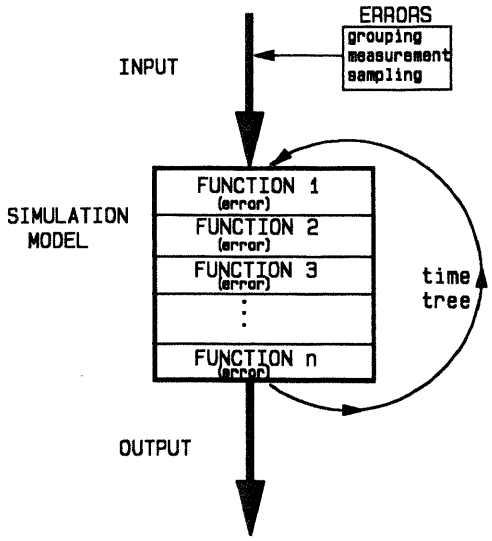

Figure 1.--Errors in simulation model.

1) Errors in measurements of state variables which are dependent on quality measurement equipment, time and budget constraints, etc.

2) Sampling errors when sampling methods are used to estimate the state variables. The errors are the result of taking only a subset of the total population when making estimates of the state variables. The size of the errors are dependent on sample size, plot size, sampling method, etc.

3) Process errors which refer to modelling errors and stochastic errors that are not accounted for by the component models.

4) Grouping errors which are due to grouping observations into classes (e.g., DBH classes). The grouping is a source of error.

Once an error budget is developed for a model, the important sources of error can be ranked in terms of their contribution to the variance of predicted forest characteristics. Based on the budget, future model refinement, experimentation and sampling can then be directed at reducing the more important sources of errors.

STEMS ERROR BUDGET (PROCESS ERRORS)

Currently, an error budget is being developed for the STEMS model. Presented here is the portion of the error budget due to process error which has been found to contribute a major proportion of the variability in projected forest growth.

The budget was developed by projecting 40 prism plots that were taken randomly from the oak-hickory (Quercus-Carya) component of Allerton Park. Allerton Park is a mixed hardwood forest owned by the University of Illinois.

The variance of predictions made with the overall simulation model were partitioned according to the important component models to generate the portion of the error budget due to process errors. The four major individual tree models used in the STEMS model are: 1) live crown ratio function, 2) annual diameter increment function, 3) probability of regular non-catastrophic mortality (survival) function, and 4) total stem volume function. The form of the models and the specification of process errors were as defined in Gertner (1987). A simplified flow chart of the projection system is shown in Figure 2. Sampling errors in the state variables that were used to initiate the system were

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accounted for and propagated through the models, but were not partitioned. It was assumed that there were no measurement errors in the state variables.

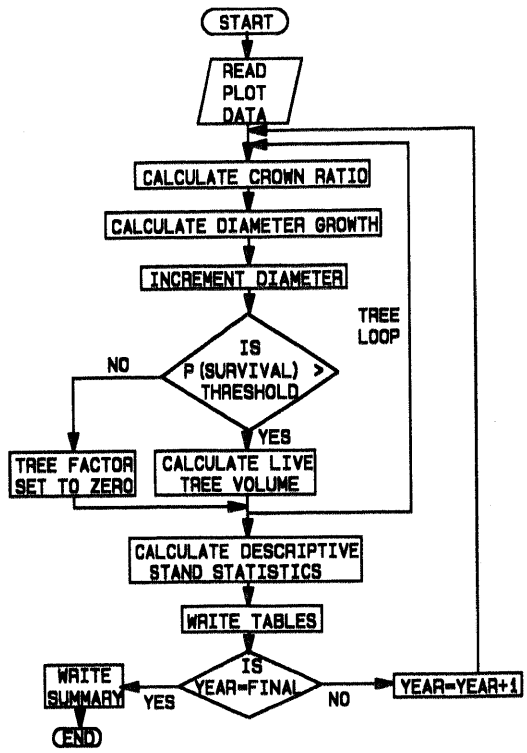

Figure 2.--Flow chart of modified STEMS projection system.

Table 1A shows the percent of variability in the number of trees per hectare versus time partitioned according to the four major individual growth models. As would be expected, almost one hundred percent of the variability in the number of trees per hectare is due to the mortality model. Other stand attributes were also greatly influenced by the mortality model. For example, shown in Table 1B is the partitioned variance for basal area per hectare. Although not as important, the mortality model is still the major source of variability in stand basal area.

Table 1A.--Percent of variability for number of trees per hectare associated with component models.

Projection Year	Live Crown Ratio	Annual Diameter Increment	Mortality	Total Stem Volume
0	0.12	0.53	99.35	0.0
10	0.11	0.43	99.46	0.0
20	0.09	0.34	99.57	0.0
30	0.08	0.28	99.64	0.0
40	0.04	0.27	99.69	0.0
50	0.02	0.25	99.73	0.0

Table 1B.--Percent of variability for basal area per hectare associated with component models.

Projection Year	Live Crown Ratio	Annual Diameter Increment	Mortality	Total Stem Volume
0	2.72	29.53	67.75	0.0
10	1.92	17.57	80.51	0.0
20	1.55	11.73	86.72	0.0
30	1.23	8.72	90.05	0.0
40	1.01	6.98	92.01	0.0
50	0.92	5.69	93.39	0.0

The results presented are not unique to the particular data set. Similar results were obtained with projections made for other stands and county wide inventories from locations in both Illinois and Wisconsin.

FUTURE RESEARCH

Currently, the model used to predict the probability of annual mortality is a logistic model used in its stochastic form that overwhelms all other component models in the STEMS system. It is fairly well known that the art of modeling individual tree mortality is very poor (i.e., Buchman et al. 1983; Hamilton 1986 and 1980). With the error propagation method, the significance of not being able to model mortality precisely becomes apparent.

Based on the results presented here, future research should now be directed toward improving the ability to predict regular mortality. Even a marginal improvement in the mortality model would lead to a significant improvement in the precision of predictions made with the overall STEMS model.

There are a number of different approaches that might be taken to improve the mortality model. Some possibilities are as follows:

1) The collection of new data to supplement existing data, via samples or experiments, should be considered for improving the logistic model. Currently the data collected for the mortality model is deficient because the range of predictor variables is limited due to clustering and previous long-term experiments not being designed for the purpose of calibrating a logistic mortality model.

2) The inputs used for the mortality model are those that are typically collected in mensurational surveys. These variables might not be adequate for the purpose of modeling mortality. More detailed measurements, including the measurement of physiological variables, would potentially improve the precision of the logistic model.

3) Although STEMS is not a process model, consideration should be given to developing a mechanistic mortality model. If this is done, the goal should be to understand the physiological process of non-catastrophic tree mortality so that a deterministic mortality model can be developed.

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