In February, 1972, American Forest Products Corporation and the University of California Forest Products Laboratory entered into a cooperative research program with the goal of maximizing the return from AFP's lumber drying system. This research program consisted of basically four phases of study and analyses:

I. Description and Analysis of the Present System

The purpose of this first phase is to completely clarify, define and indicate the implications of each step of the drying operation as they apply to the total drying system. It was felt that this first phase is extremely important because an improved drying system can only evolve after a careful evaluation of the present overall operation has been made.

II. Experimental Evaluation of Kiln Operations

The first part of this phase was an analysis of segregation practices as they relate to drying uniformity, drying time and degrade losses. After reviewing this information, it became desirable to experiment with nuclear, microwave, sonic and other types of moisture or wet density monitoring systems to determine the feasibility of improving green chain segregation practices.

The second part of this experimental phase was an evaluation of known kiln operation systems. This included evaluations of sensing systems; for example, in-kiln load cells, systems to measure board temperature, temperature and/or humidity drop across the load, and systems designed to measure the moisture content at various locations within the kiln charge.

This phase also included an analysis of kiln controlling systems, such as optimized manual stepwise control, cam controllers, and complete automation of kiln controlling by feedback from sensing units in the kiln to a programmed computer controller.

III. Operations Analysis of Alternative Drying Systems

IV. Implementation of Investigative Results

For purposes of this presentation today, we will concern ourselves only with the experimental phase of this cooperative study. I will briefly describe two areas of our studies that I find extremely interesting. The first area has to do with improving the green chain segregation, and the other has to do with computer controlled dry kilns.

We first looked at all the variables nature puts into a piece of wood that will affect the drying rate of that piece of wood. Some of these
variables are: specie, original moisture content, specific gravity, thickness, slope of grain, and growth rate. If we play with all these variables mathematically, we can place a value on each variable and then try to predict the drying rate of any individual specimen.

Figure 1 shows the equations of the curves that were developed by plotting drying time against the variables of weight per square foot surface area, original moisture content, specific gravity and thickness. The $R^2$ values developed by measuring all of these variables for each piece of lumber coming from the sawmill indicate a high success rate in predicting the drying rate for each piece. However, it is impractical to measure all these variables on line in the typical sawmill environment, if not impossible. But we can measure the weight, the thickness, the length and the width of each piece, and a small computer can then calculate the weight per square foot surface area of each board.

Figure 1 also shows an $R^2$ value for this variable alone that is surprisingly high. With the pine species we can consistently predict the drying rate with a 90 percent accuracy rate when given only the weight per square foot of the surface area.

With this information, we can program the tray sorter to sort lumber into drying sorts based on ranges of weight per square foot, instead of the conventional heart-sap or corky-sinker methods. Previous experience has shown that heart-sap or corky-sinker segregations made by the tray sorter operator have marginal success rates at best.

Figures 2, 3, and 4 show the population distribution of the weight per square foot measurements that we made for each specie that we were concerned with. In each case definite sub-populations were present which indicated possible sort limits. As an example, sugar pine population would suggest a sort limit of 5.8 pounds per square foot. All boards which weighed less than 5.8 pounds per square foot would be placed in the corky sort, and all boards over 5.8 pounds would be called sinker. Using this system, the tray sorter operator does not have to make a drying sort decision, which allows him to do a better job of grading and trimming.

Figure 5 shows a typical result when we compared the corky-sinker mill sort as a control to the sort made using weight per square foot as the sole criterion. These two groups of boards were dried in the same crib of lumber with the same drying schedule. The test group shows a significant improvement in the final moisture content distribution. Those boards to the right of the control population can be identified as those boards that were called corky by the tray sorter operator, but that had a "sinker" type drying rate.

The benefits of this type improved drying sort capability are obvious: less redry, less overdry, less degrade, less slop built into drying schedules; and because of these benefits the most important benefit - a greater dollar return to the company.

The degree of accuracy of this system is around 90 percent for the pine species. However, with white fir, the accuracy rate drops to
around 75 percent. We feel that sinker pockets, smaller logs, mixed heart and sap in the same pieces, and high elevation growth habitat may explain the lower accuracy rate with this specie. We do feel, though, a 75 percent accuracy rate is a significant improvement over visual, non-human segregation practices we now employ.

The hardware required to put this system on line is now in the design stage, with a target installation date of fiscal 1977.

The other part of the experimentation phase of our cooperative study with the California Forest Products Laboratory that I would like to discuss today concerns computer controlled dry kilns.

Historically, softwood lumber has been dried, using the time-temperature schedules that have been developed by trial-and-error methods over long periods of time. Usually, the dry kiln operator uses a schedule which produces minimum amounts of redry and one that is always ready to pull on the day shift in the morning when the ambient temperature is cool and comfortable. For the most part, we really do not have any day-to-day information as to what is happening in each dry kiln. One cannot help but to wonder if we are doing the most efficient job of drying lumber when the dry kiln is, for all practical purposes, a "magic black box," Figure 6.

Of the various gadgets or systems or kiln control methods available today, the one that seemed to us to be the most interesting is a method that was originally explored by Wengert and Evans in a 1971 issue of the Forest Products Journal. They discussed the possibility of controlling dry kilns by measuring the weight change of a unit within the charge as the lumber dried.

The advantages of such a system seemed endless. The most important being a reduction of the human influence in the system. We can eliminate forgotten setups or charges not pulled at the right time. We can reduce the influence of trial-and-error drying methods. We can accurately control the drying rate and, therefore, the degrade development. We may even save some drying time, which means more production and less energy consumption.

The California Forest Products Laboratory developed a prototype system which is now in full-time use at the Martell, California complex of American Forest Products Corporation. The important features of this system are shown in Figure 7. A crib of lumber is stacked on a specially designed kiln truck which has four electronic load cells built into it. (In an actual production system, these load cells would be buried beneath the kiln track, which would eliminate the special kiln truck.) The signal from the load cells is transmitted to a summation box, and then is transmitted to a computer or other adequate controlling device which is also receiving wet bulb and dry bulb data inputs. The weight loss signal also is transmitted to a printing recorder for accurate record keeping abilities. The computer than signals the wet bulb and dry bulb automatic control system already built into the average dry kiln to set the drying conditions for the particular weight according to a predetermined schedule.
We have also located at strategic positions in the kiln several thermocouples designed to constantly monitor internal board temperature and to measure air temperature drop across the load. This information is fed into the printing recorder for a permanent record of the actual conditions inside the kiln at all times during the drying cycle.

When all this information is plotted on a graph, Figure 8, we have a reasonable picture of what is happening inside our "magic black box." By observing the rate of weight loss and the number of pounds of water evaporated per hour, we may see areas of potential improvement in our drying schedule. We may find areas of reduced water removal rates where we can increase the wet bulb depression and not suffer any degrade losses. It is unlikely this level of drying efficiency could ever be reached by the trial-and-error method.

After we have streamlined all of our drying schedules to the best of our abilities with the use of this equipment, we can program a mini computer with these new weight-temperature schedules and allow the computer to control the drying operation.

The computer will be able to make all the unseen, but necessary, schedule changes to reflect changes in moisture content or other variables from charge to charge. As the weather changes from cold and foggy to hot and dry, the computer will adjust the kiln conditions according to the drying rate of the individual charge in the kiln, as it is influenced by the outside environment. If the charge is drying faster than normal, the computer will sense this and shut the kiln down as soon as the charge is ready, thus avoiding the possibility of severely over-drying the lumber resulting in substantial degrade.

On the other hand, if we lose steam pressure for some reason, the computer will instruct the kiln to hold its present wet-bulb, dry-bulb settings until the steam pressure returns to normal and the drying rate returns to schedule. In a manual set system, the operator may make his setups according to his schedule, regardless of the steam pressure. When the steam does come back to the kiln, the wet bulb depression may have been increased beyond the desirable level with respect to the lumber moisture content which might cause internal checking or other types of degrade.

It appears to us that this system could be used to maximize production in almost any kiln complex with an accurate and customized treatment of each charge. This system can produce consistently desired dry lumber with a minimal degrade, waste of energy and manpower.

The equipment required to use this system is for the most part readily available. We have estimated a cost of $4,000 to $5,000 per track for a 15-track installation. The single largest expense would be the mini computer for the entire complex. The next largest expense would be locating the load cells under the floating sections of kiln rail.

In conclusion, I would like to say:

If we were able to sort all our lumber into accurate homogeneous drying sorts with the weight per square foot surface area system,
described earlier, and then dry those homogeneous sorts in our futuristic computer controlled dry kilns, we could all spend our time on other projects like how to dry lumber or produce steam without using non-renewable energy sources, or polluting the environment with combustion by-products.

Figure 1. Summary Results of Drying Rate Predictive Equations.

<table>
<thead>
<tr>
<th>Equation</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ponderosa Pine</strong></td>
<td></td>
</tr>
<tr>
<td>$DT = 1,393 \ (WT)^{1.313}$</td>
<td>.894</td>
</tr>
<tr>
<td>$DT = 3,614 \ (WT)^{0.618} \ (MC)^{1.313} \ (S6)^{0.641} \ (T)^{0.371}$</td>
<td>.933</td>
</tr>
<tr>
<td><strong>Sugar Pine</strong></td>
<td></td>
</tr>
<tr>
<td>$DT = 1,343 \ (WT)^{1.586}$</td>
<td>.904</td>
</tr>
<tr>
<td>$DT = 1,159 \ (WT)^{1.055} \ (MC)^{0.454} \ (S6)^{0.235} \ (T)^{0.104}$</td>
<td>.948</td>
</tr>
<tr>
<td><strong>White Fir</strong></td>
<td></td>
</tr>
<tr>
<td>$DT = 3,350 \ (WT)^{1.220}$</td>
<td>.743</td>
</tr>
<tr>
<td>$DT = 34,680 \ (WT)^{-0.506} \ (MC)^{-0.867} \ (S6)^{1.374} \ (T)^{1.608}$</td>
<td>.773</td>
</tr>
</tbody>
</table>

QUESTIONS AND ANSWERS

Q. You talked about degrade, how do you follow the progression of degrade and relate it to your schedule changes?

A. We have run several degrade studies and I won't get into the best method. We tried a few changes during the degrade study but it hasn't made any difference. Basically, we know what causes degrade and we can avoid those types of conditions in the kiln to reduce the degrade.

Q. If you have 4 or 5 kiln cribs would your equipment work as efficiently as on one?

A. Our kilns are 120 feet long with seven 16 foot cribs. Our test equipment is measuring the weight loss on one crib and this crib is the only one determining degrade. The weight loss in one crib determines the wet bulb and dry bulb settings for the entire charge. Hopefully, our kilns are tight and our thermal systems accurate enough to reflect a true picture.

Q. Did you measure a crib at different locations in the kiln?

A. Due to the physical restraints, our crib is always in the same position. We tried to pick our best kiln having uniform heat supply across the length and air velocity along the length of the kiln.

Q. Your first slide showed some variations (Figure 1).

A. There were two lines for each species. The first one developed an $R^2$ based on all the variables, the second showed the $R^2$ for
Figure 4

5/4 SUGAR PINE, SHOP & BETTER

CORKY MILL SORT

SINKER MILL SORT

Figure 5

5/4 SUGAR PINE, CORKY

TEST (wt/ft² SORT)

CONTROL (MILL SORT)

FINAL MOISTURE CONTENT, %
INPUTS
1. GREEN LUMBER
2. DRY BULB SETTINGS
3. WET BULB SETTINGS
4. TIME

Figure 6

PROGRAM

DRY BULB & WET BULB AUTOMATIC CONTROL

LOAD CELL INDICATOR
SUMMATION BOX

D.P.M.

Figure 7
Figure 8

5/4 WHITE FIR, SHOP SINKER

WEIGHT, THOUSANDS OF POUNDS

TEMPERATURE, °F

WATER REMOVED, POUNDS

HOURS

D coach BULB

WET BULB

TEST CRIB WEIGHT

11% MC
just weight per square foot. We cannot measure the specific gravity and density and all the variables on line in the sawmills. We can measure the weight, thickness, length and width of the boards.

Q. What does weather have to do with kiln schedules?
A. Probably very little, other than when environment is cold and high humidity. The conditions of air brought into the kiln is bound to influence the rate of water removal from the wood, if you have to warm and dry the outside air.

Q. Although you didn't quite use the term, were you separating your lumber on the basis of density? Segregating of lumber on the basis of density, you find that your dense material presumably takes longer to dry. I'm a little confused because we tried some experiments at our lab on this basis and in some cases we had a good correlation. In one or two cases the heavy material took longer to dry than the lighter material and in other cases we could absolutely find no separation at all. We found this not a viable approach with the inconsistency in our results.

A. Here is where we take it out of our laboratory and put in into practical everyday drying conditions. Our sawmill cannot produce lumber of consistently accurate thickness and width. If every piece had the same volume as opposed to density this wouldn't truly reflect the picture. A thin sinker type board may dry the same as a thick corks type board and these are the types of things that would show up on this system. A board with higher moisture content will weigh more per cubic foot than a higher density board with low moisture content. If you have a lot of summerwood the board will be denser but may not have a low moisture content. Perhaps, a better term would be wet density, if you consider the moisture content, density, and thickness of the board, then this system can be reasonably accurate, giving us a $R^2$ value of 0.9 on a pine species.

Q. Are you just doing this on a pine species?
A. Yes, but we used Ponderosa pine, sugar pine and white fir, Abies concolor.

Q. The procedure works for pine, but with west coast hemlock, we don't find similar circumstances.
A. I would agree with you because we noticed on our white fir, similar to hemlock, we experienced not as good a relationship.