In-Line Moisture Content Measurement of Kiln-Dried Lumber for Process Improvement

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Abstract

The in-line moisture meter at the planer measures the moisture content of every board. This information is often not used for process improvement because of difficulty in linking the moisture information to a point in the process and reliable statistical methods for analyzing the data. Test programs in which the moisture contents measured at the planer were used to create process charts for kilns and to identify kilns or zones within kilns with high moisture content or moisture content variability were established in four mills. Tagging units, either with bar codes or with alphanumeric tags, to identify their location in a kiln was a practical and effective way to diagnose kiln performance when the moisture content information collected at the planer was associated with location. Wet areas and dry areas could be identified, and the consistency of moisture content from charge to charge could be evaluated, as could the variability within charges. The latter items can be accomplished without knowing the location of a unit in the kiln if the kiln from which the lumber came is known at the time of planing. The methods developed also allow other factors, such as operator decisions and the performance of in-kiln moisture meters, to be evaluated.

A goal for many softwood-dimension lumber-drying operations is to get each board to a moisture content of 19 percent or less to meet the grading rules. The boards are dried in large batches, and for 95 percent of the boards to be under 19 percent often requires that the mean moisture content be in the range of 11 to 15 percent. Mills try to keep the mean as high as possible to minimize drying time, energy consumption, and the increased warp associated with lumber at lower moisture contents. The same problem exists for other softwood lumber, but the moisture requirements might be more rigid, for example, less than 12 percent with no pieces over 15 percent moisture content.

The board-to-board variability makes estimating the moisture content of the lumber at the kiln difficult. The standard deviation is often in the range of 2.5 to 5.5 percent. A large number of boards must be sampled with a handheld moisture meter to get a reliable estimate, and the way the lumber is stacked makes random sampling difficult. Operators often take 200 to 300 readings. In-kiln capacitance-based moisture meters help by measuring a large number of boards, but factors other than wood moisture content affect the correlation of the average moisture content measured by the in-kiln meter to that measured by the in-line meter at the planer.

Most softwood mills have an in-line moisture meter at the planer and check the moisture content of every board prior to sorting. The wet boards are dropped out and redried in a few mills, but in most mills there is no segregation, and the in-line meter serves as a check of the process. Mills can investigate the drying process if too much wet or overdry lumber occurs and attempt to determine a cause. This can be challenging because all the lumber from a kiln charge is not always run sequentially through the planer. Often boards of multiple lengths and widths are dried together. The planer can handle only one width at a time (for dimension lumber), and the number of sorting bins may limit how many lengths can be run on a given shift. Thus, mill personnel may not know exactly where the problem occurred in a facility with multiple kilns.

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Lumber that is planed while too wet and then sorted out may have a lower value because it will be undersized after drying. If it is sorted before planing, there is a cost associated with handling if it is redried or allowed to air dry before rerunning. In cases where the wet lumber is not sorted at the planer, there is no direct value loss in the short term. Still, one must assign a cost if the wet lumber results in lost customers or wet claims. Lumber that is too dry when planed is more likely to have warped. The value loss has been estimated at 1 percent of the lumber value for each percent that the moisture content is reduced below 15 percent (Bassett 1973, Milota and Wu 1997). Planer production will likely be reduced with drier lumber because of a tendency for more planer jams. It is in the best interest of the mill to minimize the moisture variability in kiln-dried lumber to reduce the amount of lower-value lumber produced when overdrying and underdrying occur. Also, the mill can dry to a higher final moisture content if the variability is reduced and increase production while saving energy and possibly improving quality.

The information from the in-line moisture meter at the planer tends to be underused. Very few mills do more than look at the mean and variability, and fewer attempt to relate the information back to the process. The objective of this work was to develop techniques for tracking kiln performance based on the information available from an in-line moisture meter at the planer. There were two aspects to this. One was using statistical process control techniques for charting the drying process to minimize charge-to-charge variability. The other was using the moisture content information for detailed diagnostics of kiln performance to minimize the variability within the kiln.

Literature Review

Modern quality control has its origins in the 1920s with the development of control charts by Walter Shewhart (Grant and Leavenworth 1988) with further refinement during the war in the 1940s. Interest in quality control in the United States then fluctuated until the 1980s. The importance of quality in profitability has since been recognized in most industries.

Control charts are usually in pairs and viewed one above the other with their abscissas having the same scale of time or subgroup (sampling period) number. Subgroup averages ($\bar{x}$) of about five measurements are placed on the upper graph (x-bar chart), and the difference between the largest and smallest value in each subgroup is placed on the lower graph (R-chart). There are three lines on each chart: the central tendency, an upper control limit, and a lower control limit. The control limits are statistically determined from the range and sample size and are conventionally placed approximately three standard deviations from the lines of central tendency. There is a low probability of a point occurring outside the control limits, and corrective action should be taken when this occurs. The charts are a simple visual way to monitor a process.

Rietz (1949) presents statistical process control (SPC) techniques for kiln-dried lumber as it enters a furniture plant, and Latimer (1951a) discussed the present state of quality control in wood products in the first issue of the *Forest Products Journal*. Latimer (1951b) describes two methods of applying statistical process control to kiln-dried lumber. One is an acceptance sampling for units of lumber entering a remanufacturing facility. Four moisture content samples were taken with a handheld moisture meter every few layers during unstacking. The difference between the sum of all readings and an acceptance value was plotted after each set of samples. This formed a line that needed to remain within certain limits, or the unit was rejected. The other method described by Latimer (1951b) was for sequential kiln charges. Twenty-five moisture meter readings were taken with a handheld meter, and the average and range were plotted. Control limits based on the Shewhart principles were included on each chart. Latimer (1951b) used the range chart to obtain the limits for the x-bar chart, a technique that is strictly valid only if the moisture contents of the samples are normally distributed. This is probably the earliest article showing the application of x-bar and R-charts for the kiln-drying process. Pratt (1953) presents similar work for redwood.

Rice (1976) discusses techniques for measuring the moisture content in packages of hardwood lumber. His data are summarized in tabular form rather than SPC charts. His work is different from past work, however, because he tracks the moisture content of individual packages, and patterns of moisture content can be identified within a kiln. Wengert (1987) furthers this concept and discusses a technique for determining the standard deviation within units and between units and the overall standard deviation, all based on handheld moisture meter readings. He also discusses variation as a function of position within the kiln.

Bramhall and Warren (1977) discuss the use of in-line meters at the planer for gathering the data for SPC. In-line meters were a relatively new development at the time, and they elected to base their program on data collected with a handheld meter because it most closely represented the practices of the grading agencies. Two charts were created—a chart of averages and a chart of nonconforming pieces—and rules were given for when the process was behaving abnormally. They considered 200 measurements per charge to be the minimum number for accuracy.

Maki and Milota (1993) present techniques for plotting the mean and variability of moisture content using pin-type handheld moisture meters. A charting technique was developed for a multizone kiln that was capable of identifying zones that are consistently dry or wet compared with other zones in the kiln. They cite the time required to take readings and the difficulty with getting a random sample as disadvantages. In what was probably the first attempt to apply SPC to stacking practices, the authors also present an attributes chart for sticker alignment.

The shape of the moisture content distribution must be normal for traditional SPC calculations to be strictly valid (Grant and Leavenworth 1988) because the sample range is used to calculate the control limits for the sample mean. Moisture content data are often not normally distributed and tend to be skewed to the right (toward the higher moisture contents) because the equilibrium moisture content limits the tail on the left side of the distribution. Maki (1991) discusses methods for transforming nonnormal moisture content data. A log transformation changed the skewness from 0.49 to −0.29 for Douglas-fir and 1.07 to −0.05 for ponderosa pine. He concludes that the skewness was improved by the log transformation; however, he indicated that outliers (very wet boards that form a long right tail) are better handled with the reciprocal transformation. He presents control charts for three kilns for which the control limits are derived from a reciprocal transformation of the moisture content data.

Most of the earlier work did not use a transformation. Latimer's (1951b) work was on hardwood lumber with a low moisture content and small variability compared with dimension lumber. Pratt (1953) notes the right skew in the moisture distribution but ignored it when using the range to establish control limits on the x-bar chart. Much of the earlier work was done at lower moisture contents and with less variability than is seen in modern-dimension lumber, and the nonnormality was less significant.

Whereas Maki (1991) investigated a two-parameter log transformation, Ristea and Maness (2005) proposed a three-parameter log transformation for kiln-dried lumber. The three-parameter distribution accommodates right-skewed distributions for which the lower limit is greater than zero. This limit might be the equilibrium moisture content at the end of the kiln cycle; however, the limit is not known if drying is stopped before some boards approach the equilibrium moisture content. Ristea and Maness used the maximum likelihood method of Cohen (1951) and Cohen and Whitten (1980) to estimate the lower limit of the distribution for this case. After the distribution was transformed, they were able to use the traditional SPC methods (Grant and Leavenworth 1988) to create control charts. They did a reverse transformation so that the charts could be plotted in moisture content units rather than log units, making them much easier to interpret and leading to a US patent (Ristea et al. 2006).

In summary, statistical process control on lumber kilns has been done using handheld moisture meters. This has generally worked for a low-moisture-content product with low variability. Obtaining a random sample at the kiln is difficult. The in-line moisture meter at the planer is capable of measuring every board. This information is not currently used to control and improve the process in a systematic way.

Procedures

Four mills were solicited as cooperators in this work. Procedures were established in each mill to collect data from the in-line moisture meter at the planer and from the kilns. Packages of lumber were tracked so that the kiln and, in most cases, location in the kiln were known. Charts were then constructed for moisture content and moisture content variability among and within the kiln charges. Where possible, the drying was related to other factors, such as storage time before or after kiln drying.

Mill setup

All mills dried either studs, dimension lumber, or both. The mill descriptions presented here are not detailed to obscure the identity of the mills. Mill A dried western hemlock (*Tsuga heterophylla*) and Douglas-fir (*Pseudotsuga menziesii*) in two kilns. One kiln was relatively new, and the other was older and in poor repair. Mill B dried western hemlock in two kilns. Mill C dried southern pine (*Pinus* spp.) in three kilns. Mill D dried Douglas-fir, western hemlock, and other species in eight kilns. All kilns held two tracks of lumber and had reheat coils in the center.

Mills A, B, and D had a handheld PC built into a Intermec CK-31® bar-code scanner for use at the kilns. The PC contained a spreadsheet-like program custom written so that the individual cells corresponded to specific locations in the kiln. The location of each unit of lumber in the kiln (the configuration) could be recorded by scanning a bar code on each unit of lumber into the correct cell. Mill C placed an alphanumeric tag onto each package. The tags were in a specific numeric sequence relative to the unit location in the kiln. The configuration included other relevant information, such as the length, width, thickness, and species of the lumber in the unit. The kiln start and stop times were recorded and in some cases the date the unit was stacked in the sawmill.

Each mill had a Wagner Apex® moisture measurement system in-line either before or after the planer and InfoPak® software. The moisture meter is a noncontact meter and measures either the full length of the board (for end-to-end flow) or three to four locations on a board (for boards in cross flow on a chain). The software communicated with the moisture meter to capture the average moisture content of each board.

The configurations scanned at the kilns could be directly transferred into the InfoPak® software from the handheld PC using Microsoft ActiveSync®. The configuration for the alphanumeric tags could be input by entering the first number in the tag sequence. The software would then autofill the tag numbers.

The three mills that used scanners at the kiln also had a Motorola Symbol® P370 bar-code scanner at the breakdown hoist. The bar code on a unit of lumber was scanned after it was placed on the chain for the breakdown hoists and before the moisture content was measured. This placed the bar code into a queue. Several units could be scanned in the order they would be run if they were on the chain awaiting breakdown. The operator made a ultraviolet (UV) crayon mark on the first board from each unit when it passed on the chain. The first bar code in the queue became the active unit when a sensor at the moisture detector saw the UV mark. The bar code was transmitted to the software, which then made the association between the bar code scanned at the planer and the bar code scanned during the kiln configuration. The process was similar for the alphanumeric tags except that the tag number was hand entered at a console located near the planer operator. This mode of operation in which the location of each package is known is denoted as ''diagnostic mode.''

An effort was made to have the data collection be integrated with normal mill operations and to cause as little disruption as possible. In some cases, the procedures had to be changed to accommodate this. An example of this is eliminating the unit tags in cases where all the units in a kiln charge are run through the planer consecutively. Procedures were changed in this case so that a number representing the charge was entered when the first unit reached the moisture meter. Each new unit was then triggered with a UV mark or other signal. This mode of operation is known as ''standard mode.'' The location in the kiln is lost in this mode, but the variability within and between packages is known.

A ''simple mode'' of operation was also tested. In this case, the kiln charge is run as a batch. The ability to distinguish between within- and between-unit variability was lost; however, the breakdown hoist operator did not need to signal the start of a new package, thus simplifying the data collection at the planer.

Data collection and analysis

After the equipment in each mill was tested, the data collection period ranged from 5 to 10 months. During this time, the mills configured charges at the kiln and performed the scanning or data entry at the planer. The data were downloaded weekly, and mills were provided with periodic reports. The available data included the average moisture content for each unit (M_U) and the standard deviation among the boards within each unit (s_U). Units with approximately 30 percent too few or too many boards compared with how many boards the mill places in a unit were not used in further calculations. This occurred when the operators did not make a UV mark, the reader missed the UV mark, or a stray UV mark was detected. The entire charge was deleted from the data if less than 50 percent of the units in the kiln configuration were not accounted for at the planer.

The average moisture content for a kiln charge was calculated from the package averages (Eq. 1):

$$M_C = \frac{\sum_{U=1}^{U=n} M_U}{n_{UC}}. \qquad (1)$$

No weighting was done for the number of boards in each unit. The standard deviation among the units was calculated as

$$s_{AU} = \left(\frac{\sum_{U=1}^{U=n} M_U^2 - \frac{\left(\sum_{U=1}^{U=n} M_U \right)^2}{n_{UC}}}{(n_{UC} - 1)} \right)^{0.5}, \qquad (2)$$

the standard deviation within units as

$$s_{WU} = \left(\frac{\sum_{U=1}^{U=n} (n_{BU} - 1) \cdot {s_U}^2}{(n_{BC} - n_{UC})} \right)^{0.5}, \qquad (3)$$

and the total standard deviation as

$$s_{TC} = \left(\frac{{s_{WU}}^2 + {s_{AU}}^2}{n_{BC}} \right)^{0.5}. \qquad (4)$$

The x-charts were created with the charge moisture content on the ordinate and the date on the abscissa. A chart showing the range of package moisture contents in the kiln was used in place of a conventional range chart. The package range was the difference in moisture content between the wettest and driest units in a charge. Charts were also created for the standard deviation among the units in a charge and between units within a charge.

The moisture content in each control zone in some kilns was calculated. This was based on the average moisture content of the units in the zone. For calculation purposes, a unit that resided in more than one zone was assigned to whichever zone contained more than half the unit. The zone moisture contents were compared with examine the variability in the kilns by location. A wet region in a kiln could be a one-charge occurrence and related to the wood or the stacking. To identify mechanical problems that affect consecutive charges, the moisture contents for a zone for several consecutive charges were averaged and compared with the other zones in the kiln.

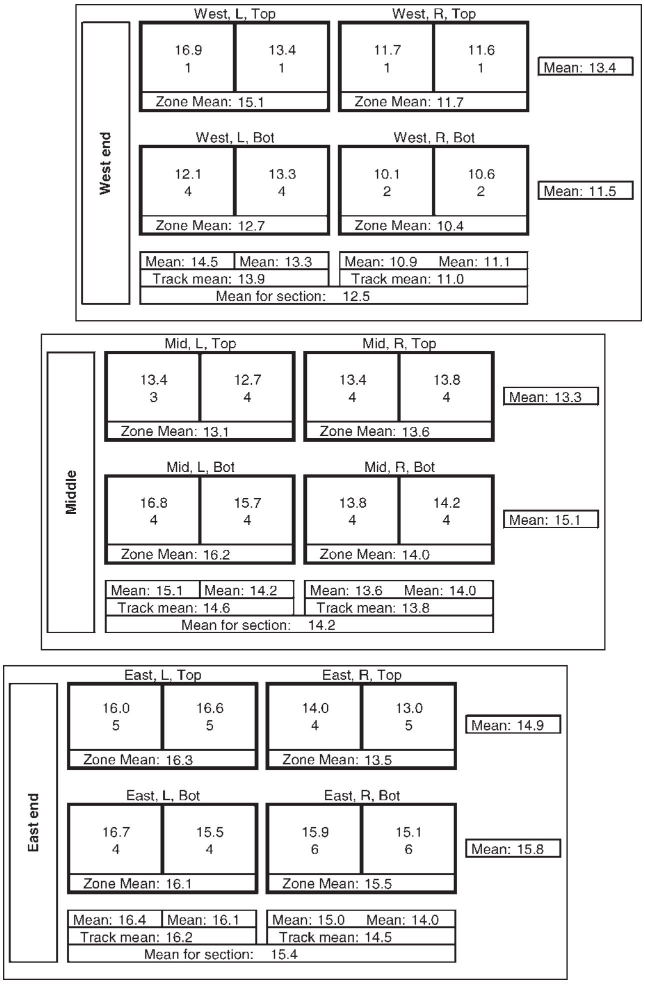

Figure 1.—Details of kiln diagnostics. The three large boxes top to bottom represent cross sections of the three end-to-end (longitudinal) control zones in the kiln. The small boxes represent the lumber on one side of a track in a longitudinal zone. Within these, the values are moisture content in percentages and the number of units included in the average. Each pair of small boxes represents a zone of control in the kiln.

Results and Discussion

Kiln diagnostics

The moisture content as a function of location in a kiln for a single charge of lumber from a kiln at Mill C is shown in Figure 1. The kiln has three control zones from end to end that are represented by the three large boxes from top to bottom in the figure. The right and left sides of each large box represent lumber on the right and left tracks. Each pair of smaller boxes (bold outline) represents the lumber within a control zone. Each of the pair represents lumber on the left or right side of the track. The units are placed two wide on a track in this case. The center heating coils in this kiln are split from top to bottom so that there are two pairs of boxes from top to bottom on each track.

It can be seen from Figure 1 that the average moisture content is 12.5 percent at the west end, 14.2 percent in the middle, and 15.4 percent at the east end. Of particular concern would be the low moisture content of 10.1 percent found on the right track at the west bottom of the kiln. Based

Average MC:	14.6
Valid packages:	1084

Length Summary	n	MC	rMC
West end	315	13.2	-1.33
Middle	367	15.3	0.82
East end	402	15.0	0.51

Track Summary	n	MC	rMC
Right:	546	14.4	-0.17
Left:	538	14.7	0.17

Vertical Summary	n	MC	rMC
Upper:	537	14.4	-0.21
Lower:	547	14.8	0.21

Average MC:	15.8
Valid packages:	862

Length Summary	n	MC	rMC
Far end	213	15.8	0.00
Third zone	218	15.8	-0.01
Second zone	259	15.8	-0.02
Near end	172	15.8	0.01

Track Summary	n	MC	rMC
Left:	424	15.9	-0.05
Right:	428	15.8	0.03

Vertical Summary	n	MC	rMC
Upper:	494	15.4	-0.46
Lower:	368	16.3	0.45

Figure 2.—Summary of moisture content variability by location in kiln over 20 (left) and 10 (right) charges. The data on the left are from the same kiln as the data in Figure 1. The data on the right are from the best performing kiln in the study.

on this one charge, one might conclude that this kiln produces wetter lumber on the east end and drier lumber on the west end.

Figure 2 shows similar information as Figure 1, except that the moisture contents at each location are averaged over several charges. The rMC (relative moisture content) column is the amount that the moisture content at that location is above or below the mean. The data on the left are from the same kiln as that in Figure 1, and the information is from 20 charges (10 before and 10 after the charge shown in Fig. 1). It suggests that the west end is consistently too dry but that the final moisture contents in the middle and to the east are similar. An inspection of the kiln showed that all the steam pipes came in from the west and that overheating is the likely cause. The average moisture content on the right track at the east bottom was 13.5 percent over the 20 charges (not shown in figure), indicating that the dryness that appeared in that location in Figure 1 was probably a result of stacking or other one-time event, not a kiln design or maintenance problem. The right side of Figure 2 shows the average moisture content by location for a kiln that is well balanced. There is almost no end-to-end variability among the four longitudinal zones and almost no difference in moisture content between the tracks. The wood from the upper part of this kiln was only 0.9 percent drier than the wood from the lower part.

The typical moisture variability observed in a kiln was between the two cases shown in Figure 2. More than 1 percent from end to end and top to bottom was common. Combined, this can mean a 2 to 3 percent difference in final moisture content from the lower part at the wettest end to the upper part at the drier end. Presenting the information as shown in Figure 2 make the variability appear smaller that what it is, but it was far easer for mill personnel to interpret than the same information (multiple charges averaged) presented in a format like Figure 1.

SPC charts

An x-chart, also called an individuals chart, was used to show trends for the charge average moisture content rather than an x-bar chart because a 100 percent sample was taken. In effect, there is one data point per charge, the mean charge moisture content, rather than an average of a few samples. The use of this chart is further justified based on the data because the moisture contents of all the boards in a charge are not independent. The large value of $\sigma_{\bar{x}}$, often 1 to 1.5 percent, compared with $\sigma/\sqrt{n_{BC}}$, which would approach zero, observed in the study suggests that charge-to-charge variability is influenced by different factors, such as the operator's decision regarding when to end drying, that do not have a large influence on the board-to-board variability. Control limits for the x-chart were based on three standard deviations of the mean charge moisture content. The mean moisture contents of charges were more or less normally distributed over time with skewness values ranging from −0.3 to 0.6. An example of an x-chart is shown in Figure 3 (top).

A traditional R-chart, on which is plotted difference between the moisture contents of the wettest and driest boards, would not be useful because the values would always be large for a large sample of dimension lumber. A chart called the package range chart was developed as a substitute. The difference between the mean moisture contents of the wettest and driest packages in the kiln was plotted. An example of a package range chart is shown in Figure 3 (second). The distribution of the package range tended to be skewed toward large values with skewness values ranging from 0.2 to 1.2. A three-parameter log transformation on the values for package range improved the normality for southern pine but either caused no improvement or increased the absolute value of skewness for Douglas-fir and western hemlock. Additionally, the standard deviation of the transformed data was on the same order as the mean of the transformed data, resulting in a very wide upper control limit when the charts were replotted back in the original moisture content units. It was therefore decided to plot the package range without a transformation.

The standard deviation of mean package moisture content was also plotted with control limits based on three times the standard deviation of the plotted value (the standard deviation of the standard deviation). An example of this chart is shown in Figure 3 (third). The use of asymmetric limits using the chi-squared parameter $\sigma\cdot\sqrt{\chi^2/(n-1)}$ would be more appropriate because it is positively skewed; however, Ryan (2000) indicates that "3-sigma limits are typically used" on a standard deviation chart for SPC. This was tried both ways, and the upper control limit tended to be quite wide when the limits were based on the χ^2 limits.

The standard deviation among packages provides essentially the same information as package range. However, for large kilns with many packages, the package range is more sensitive. For smaller kilns with few packages, the two indicators are similar in sensitivity. An example can illustrate this. Suppose one kiln contains 23 units of lumber and a second kiln contains 80 units. If all units are at 16, 17, 18, or 19 percent moisture content (equally distributed), then the standard deviation among packages is 1.0 percent, and the range is 3.0 percent in each case. If one package in each kiln was at 24 percent, the range becomes 8 percent in each case (24 − 16). The standard deviation becomes 1.8 percent in the small kiln and 1.4 percent in the larger kiln. Thus, in a kiln with few packages, both standard deviation and range are greatly affected by one wet package. In a kiln with

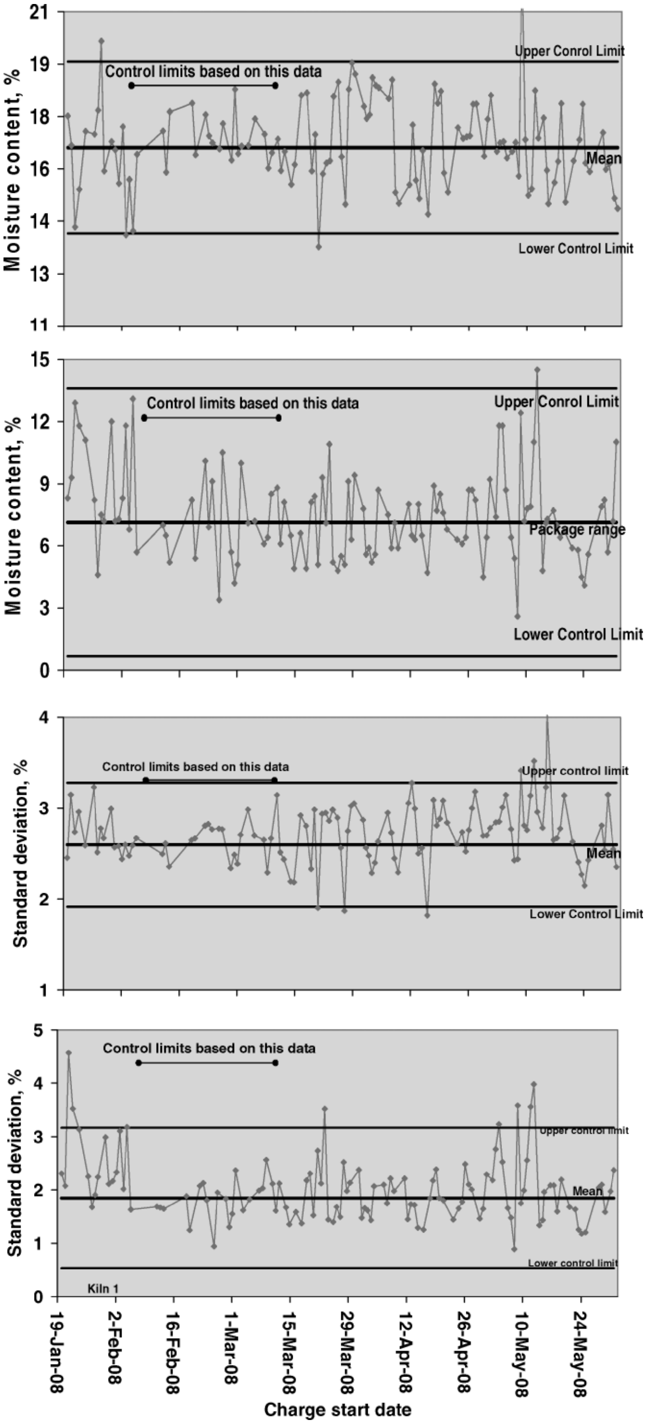

Figure 3.—The x-chart (top), package range chart (second), and standard deviation among (third) and within (bottom) units. Each point on a chart represents a kiln charge. Data are for one kiln and one species over a 4-month period.

many packages, one wet package greatly affects the range but has a proportionally smaller effect on the standard deviation.

The standard deviation within units is also shown in Figure 3 (bottom). This chart indicates variability that might arise from the properties of the wood within a package having variability. In a sawmill, this might be caused by mixing fresh logs with decked logs as they enter the sawing process or by a change in the sorting technique prior to stacking.

The charts in Figure 3 indicate that there was considerable variability among kiln charges and among the packages in the kiln prior to early in February. At that point, maintenance was performed on the heating system in some zones. The reduction in variability among the units in the kiln is apparent on the package range chart. The x-chart indicates reduced charge-to-charge variability, probably because the operators were better able to measure the final moisture content and stop the drying process at the correct time. The chart for standard deviation among units provides similar information to the package range chart. The chart for standard deviation within units was also affected. This might be because the airflow or temperature through the units was impacted by the maintenance. The charges with higher final moisture content would also be likely to have a greater moisture content variability within the units. The variability again increases in late April. This was attributed to a change in the way the units were placed into the kiln based on the length and width of the lumber. The x-chart is not much affected, but the variability among the units is affected. The variability within units also increases, probably because some units are higher in moisture content and have higher variability.

It becomes possible to compare the performance of different kilns when charts are made for each kiln. For example, at Mill D, three kilns had board-to-board standard deviations ranging from 3.9 to 4.1 percent, while a fourth of the same design and construction had a standard deviation of 4.5 percent. The higher standard deviation may have been due to a higher average final moisture content; however, it was a flag that something was different. The data also showed that the fourth kiln was taking about 4 hours longer than the other three kilns to dry and that the wood was coming out at 1.5 percent higher final moisture content. Information such as this should provide motivation for a mill to investigate and remedy the problem.

Other charts

The operator who decides when the wood is dry and pulls the charge of lumber was tracked at two mills. An example of the results from over 290 charges of lumber at one mill is shown in Figure 4. Operators B, D, F, and G average between 16.8 and 16.9 percent moisture content at the planer, and a statistical difference among them cannot be established. A *t* test confirms that lumber at the planer has a lower moisture content when operator H makes the decision to end drying ($P < 0.01$). The mean for operator A was not statistically different from operators B, D, F, and G; however, the standard deviation among the mean charge moisture contents for this operator is high. This means that the operator is less consistent from charge to charge than the others. The high standard deviation makes establishing a statistical difference more difficult. The procedures used by operators A and H should be checked. Operator G may also need additional training because of the higher standard deviation. Operators C, E, and I did not pull enough charges for any meaningful conclusions to be drawn. Similarly, at another mill there were two operators who ended charges at about 1.5 percent moisture content lower than the other two operators when approximately 30 charges were averaged for each operator.

Charges	26	55	3	78	3	42	22	54	4
StdDev, %	2.1	1.3	1.0	1.2	0.4	1.2	1.6	1.3	0.5
Average, %	17.3	16.8	17.2	16.9	15.8	16.8	16.9	16.0	16.3
Operator	A	B	C	D	E	F	G	H	I

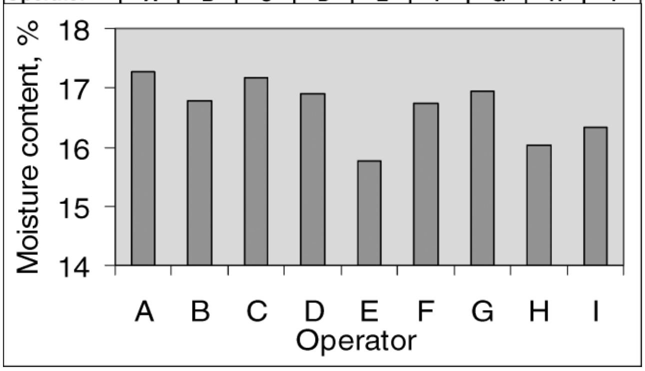

Figure 4.—Chart shows moisture content at the planer averaged over the number of charges shown in the top row. Each bar represents an individual operator at one mill, the operator who made the decision to end drying and pull the charge. Also shown at the top is the average moisture content for all charges and the charge-to-charge standard deviation.

Each mill had capacitance-based moisture meters permanently installed in the kilns. Figure 5 shows an example of the moisture content at the end of drying as determined by the in-kiln moisture meter compared with the moisture meter at the planer. There were four different models of in-kiln meters in various kilns, and Figure 5 is typical of the relationship between the measured moisture contents. They worked well for determining when the charge was near dryness, but the variability was plus or minus about 1.5 to 2 percent from the moisture content measured at the planer. A number of factors can affect this relationship, such as storage time after drying, storage conditions, time in the warm kiln after drying and before pulling, and the adjustment of the in-kiln meter. In addition, the in-kiln meters are placed in the bottom row of units in the kiln, whereas the planer average includes all the lumber. Thus, the in-kiln meter is measuring at a location that is likely to have higher average final moisture content than the kiln average. When package tracking indicated that an end of a kiln was wetter based on the moisture content at the planer, the individual probes of the in-kiln meter would also indicate this same trend. Even so, the measurement location and probe are confounded, and it would not be possible to tell probe error from a true difference in moisture content without measuring at the planer.

Figure 5 also shows the results of checking the kiln with a handheld capacitance-type moisture meter. This mill measured in each lower unit on the plenum sides of the tracks at two heights and took three readings at various distances from the side of the unit (the probe reached into the sticker slot). There were about 60 readings per charge. The variability between the moisture content measured with the handheld meter and the moisture content measured at the planer was similar to that between the in-kiln meter and planer. It is likely that mills could avoid charges that are at too high a moisture content by using both types of meters; however, this would not help when the in-kiln meter is in error the other way and the kiln is opened and hot checked after the moisture content is already lower than the target moisture content.

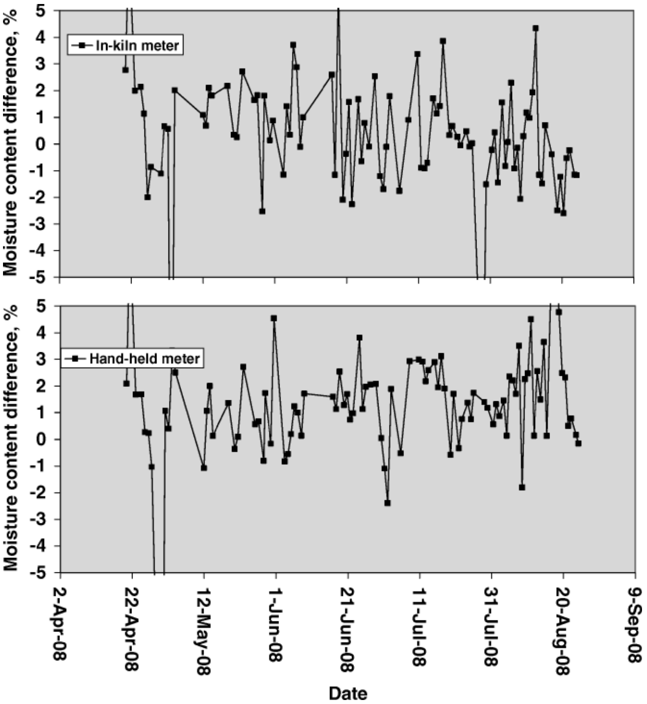

Figure 5.—Comparison of moisture content measured at the kiln by the in-kiln meter (top) and the handheld meter (bottom) to the moisture content measured by the in-line meter at the planer. A positive value indicates the measured moisture content was higher at the kiln.

Storage time between drying and planing had little or no effect on the moisture content or its within-unit standard deviation at the planer for any mill (graphs not shown). Generally, storage times were short, less than a few days; however, in some cases the poor market conditions at the time of the study caused longer storage periods. At a mill that put the heavier hemlock boards into one sort and the light boards into another sort prior to drying, the light sort was dried to 12.2 percent average moisture content, and moisture content increased slightly (but not statistically) during storage. The heavy sort was dried to 14.3 percent and tended to lose a little moisture during storage. The variability within units decreased slightly but not statistically during up to 14 days of storage.

Implementation

Some mills used bar codes on all lumber packages for inventory purposes. Generally, these were not large enough to be read on the upper units when lumber was stacked on the tracks at the kiln. A bar code 6 to 8 inches across and 2 to 3 inches high proved to be readable. Between tracks of lumber at the kiln, there may only be 10 to 15 feet of space. Thus, the bar codes need to be readable at an angle approaching 45 degrees and a distance of about 20 feet. This is at the specification limit for most bar-code equipment with the size tags mentioned previously. Other technologies we looked at, such as radio-frequency identification tagging, either were too expensive or could not survive the kiln environment.

The placement of the bar codes or numeric tags poses additional issues. The stacker operator may have difficulty safely reaching the units to place tags. If the unit is

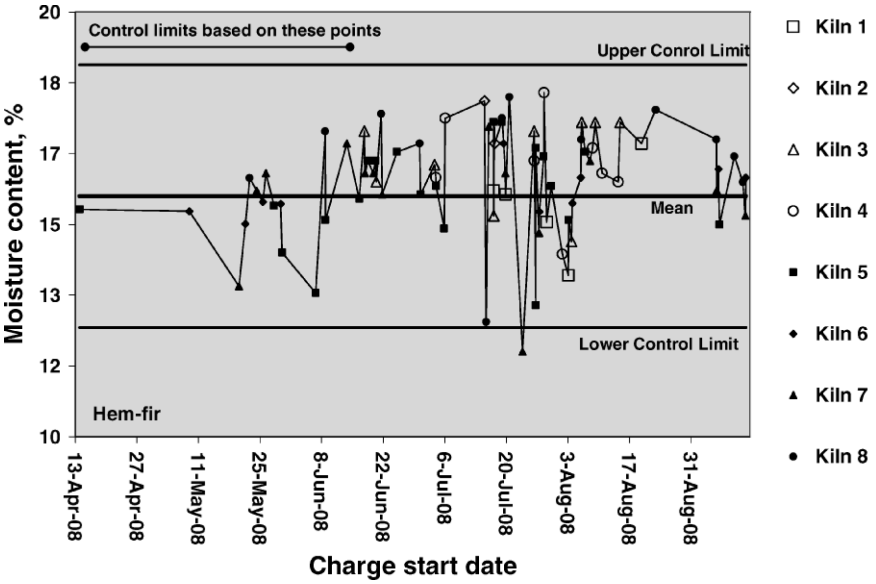

Figure 6.—The x-chart for a single species at a single mill but with multiple kilns represented.

accessible, the stacker operator can most easily reach the end of the unit to place a tag. However, the ends of the units are butted together at the kiln, making the tags unreadable without moving all the kiln carts apart. Tags can be placed on the sides of the units at the kiln, but this requires a ladder, is time-consuming, and poses safety issues. A tag placed on the side of the unit is more difficult to read at the planer, where, again, the end of the unit is more accessible to the unstacker operator. One mill solved these problems by using a tag that wrapped around the corner of the unit and could be read from two sides. Another mill placed tags as the dry units were being unstacked from the kiln with a forklift. In this case, the operators were painting information on the units, so placing the tag was a small effort because the operator already had to lower the unit and step off the forklift. Otherwise, placing the tags at the kiln requires about an hour of extra effort. Scanning takes 10 to 15 minutes if the tags are in place.

If the tags were properly placed on the units and read at the kiln, the process of determining the moisture content by location in the kiln worked very well. It made no difference if units of lumber from different kiln charges were run alternately at the planer. It is common to mix lumber from different kiln charges at the planer when different widths are dried together because the planer runs one width of lumber at a time. For some mills that ran all the units from a kiln charge through the planer sequentially without interruption, we eliminated tagging at the kiln. As long as the planer software knows from which kiln charge a unit came, all the charting can be accomplished, including the x-chart, variation within units, and variation between units. If the charts indicate that a problem exists, a mill could then start tagging and tracking.

One disadvantage of using the in-line moisture meter at the planer for statistical process control is that the data are always behind the kilns. This ranges from well under a week to about 2 weeks, depending on if mixed widths are dried in a kiln and how a mill handles its rough dry inventory. To be in real time, moisture content would have to be measured at the kiln, where access to all boards is limited. A significant advantage of using the planer data is that the SPC is for the whole sawing, storage, and drying processes.

Some of the operators felt overloaded with information if too many charts and tables were presented. However, each species and kiln combination should be charted separately for SPC purposes. At mills with several species and kilns, this can result in many charts. Placing all the data from one kiln on a chart does not work because different species have different target moisture contents and the natural variability after drying is different. The information can be consolidated by species if multiple kilns are placed on a single chart in the same way that Maki and Milota (1993) suggested. An example of this is shown in Figure 6 for hemlock dried in eight kilns. The control limits are based on data from all the kilns, so they will be somewhat wider than the control limits on charts for a single kiln. This could be compensated for by using limits at 2.5 standard deviations instead of three. For one mill in the study, this reduced the number of sets of charts from 32 to 4. It reduces the information overload to the operator and results in less personnel time spent reviewing charts. When done in color, kilns that are consistently high or low in moisture content (such as kiln 8 in Fig. 6) clearly stand out.

Conclusions

Tagging units with a number or bar code so that their location in the kiln is known at the time of measuring the moisture content at the planer is a practical and effective way to diagnose kiln performance, including moisture content variability by location in the kiln.

An alternative to tagging each package by location is to track only which kiln charge each unit came from. Knowing the final dry moisture content of each unit from a kiln charge, even without knowing its location in the kiln, provides a powerful tool for SPC. Charges with abnormal moisture contents are readily detected so that assignable causes can be determined and corrective action taken. Moisture variability, both within the units and between units, can be monitored so that changes in kiln performance or lumber handling practices can be determined.

In addition to monitoring and diagnosing kilns, the performance of in-kiln moisture meters and handheld moisture meters can be verified based on the in-line meter at the planer. With additional data collection, such as who performed a handheld moisture check or who decided to end the drying cycle, the operators' relative performance can be tracked to determine if the all personnel are operating equipment in the same manner or if individual habits are causing wet and dry lumber.

Nomenclature

M	moisture content, %
n	number of units or boards
s	standard deviation, %

Subscripts

AU	among units
BC	boards in a charge
BU	boards in a unit
C	charge
TC	total in charge
U	unit
UC	units in a charge
WC	within charge
WU	within unit

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