Development of a simulation-evaluation program for introducing and using output control in the sawmill industry

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Abstract

A computer program for simulating output control has been developed. The calculations in the program follow the standard EN 14081-3:2005, where output control is described. The purpose of the simulator is to make it possible to improve the yield without jeopardizing the safety of the produced boards by testing different approaches in grading. The program is a research tool, as well as a program to use in production where output control is used. In the program is it possible to test *e.g.* the influence of change of IP-values, number of grades, pre-grading of logs, raw material region, *etc*. The result of a simulation is shown both as diagrams and numeral. The standard C-grades are pre-programmed with K-, Y- and Z-coefficients according to the standard. Other grades can be added by the user.

1 Introduction

Output control as a method for production control of machine strength graded timber has been present in European strength grading standards for a long time. However, the machine control method is dominating and therefore little experience on how the output control method works is present in Europe. Pilot studies have earlier shown that there seems to be a potential for European sawmills to use this quality control method and get good yields in high strength classes [1].

Grading of structural timber is a compromise between yield and safety. The grading procedure shall guarantee that the graded timber fulfils all strength requirements belonging to the marked grade. The producer shall have the possibility to produce strength graded timber with a reasonable yield, without jeopardizing the safety.

A computer program for simulating and testing output control as described in EN 14081 "Timber Structures – Strength graded structural timber with rectangular cross section, part 1-4" [2] is developed, to make analysis of

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settings faster and more flexible. The program can use data from real boards or data from simulated boards. It is also possible to combine data from logs (*e.g*. information from a log scanner) with data from associated boards. Input data can be predicted strength (other than ordinary indicating property IP-values) from logs and/or boards and machine graded IP-values, which is correlated to actual measured modulus of elasticity (MOE) and strength (MOR, modulus of rupture). In the program it is possible to change IP boundaries, test yield differences and risks of being "Out of control".

The paper presents the program as well as some results of analyses of sensitivity in IP settings. One aspect presented is the method's sensitivity of variation in incoming raw material quality of the material to be graded. Another aspect presented is the results of the grading procedure if the strength graded material comes from logs which are pre-graded.

2 Background

The cusum-method for output control in the European standard 14081-3 is based on and to large extent copied from an American procedure for output control that was originally created in the late sixties and early seventies. It was aimed for a production of a few grades with a few dimensions where only one, or maybe two, grades were graded simultaneously. The situation today in Europe is another. Now a number of different grades are graded simultaneously with a large amount of different dimensions.

3 Description of Machine control and of Output control

3.1 Machine control

Machine control is the dominating method used to grade timber in Europe. Each grading machine type has an IP setting that corresponds to the wanted grade, see EN14081-4. Each grade and combination of grades needs a special setting, which means that the IP value for one grade is depending which other grades are graded at the same time. When determining the IP values, an initial test of at least 900 boards is needed. The tested boards should be representative for the region for which settings are determined. In machine control it is not allowed to change the settings to improve the yield. This means that the settings must consider the difference in correlation between IP value and strength to fit the whole population in the region.

3.2 Output control

Output control put the responsibility more on the producer of the boards than on the grading machine. In output control of structural timber a test scheme is used that follows the standard EN14081, to ensure that timber that doesn't fulfil the requirements for structural timber doesn't leave the sawmill.

Initial settings shall be tested by proof loading "a random sample of 60 specimen of each combination of strength class/species/size/source combinations" in accordance with EN 14081-2. To test the production ten specimens from each class produced during each shift shall be proof loaded to

determine MOE and check for failure. The results are entered on the control charts, together with the cusum constants K, Y, Z, according to EN14081-3.

As long as the control charts indicate that the production is in control, the sample rate is ten specimens per grade, species and shift. If the control chart indicates that the production is not in control, another routine is used. After calibrating the equipment and checking for accurate settings of the grading machine 30 specimens, six groups with five specimens each, shall be selected and proof loaded.

The results follow an "Out of control" chart, and the production can be said to be "Under observation", which is a new phrase for groups that are calculated according to the "Out of control"-chart, but have not yet reached the "Setting adjustment" phase or are "In control" again.

If calculation shows that production is in control after one or more groups, the production can continue. If production still is not in control after six groups, the settings may be adjusted by a maximum of 5 % and the process is said to be in a "Settings adjustment" phase (even if it is decided not to change the settings). In the "Setting adjustment" phase six new groups with 5 specimens in each shall be selected and tested. If charts show that the production now is in control, the production can continue and the graded material can be released. If production still is not in control, a larger settings adjustment must be made, the graded timber cannot be sold as the marked grade and new initial tests must be performed.

4 The cusum program

4.1 Introduction

The purpose of the simulator is to make it possible for a sawmill to improve the yield, without jeopardizing the safety of the produced boards, by testing different approaches in grading. The program can also be used as a research tool, as well as a program to use in production where output control is used.

In the program is it possible to test *e.g.* the influence of change of IP-settings, number of grades, pre-grading of logs, raw-material region *etc*. It is also possible to see correlations between MOE and other parameters, *e.g*. MOR, IP log, density, width, and thickness. The result of a simulation is shown both as diagrams and in figures. It is possible for a user to use "own" data and also to select sub samples of the total data set.

4.2 Dataset

To test the program a number of datasets were computer generated. Each dataset comprises 20,000 boards. The master dataset is according to Table 1 and Table 2.

Table 1: Mean values, coefficient of variation and 5th-percentile of the master dataset.

	MOR	MOE	Density	IP
Mean	44.9	12,503	450	14,788
CoV	0.35	0.26	0.12	0.22
5th-percentile	24.2	7,930	361	10,133

Table 2: R^2-values of the master dataset.

	MOR	MOE	Density	IP
MOR	1			
MOE	0.57	1		
Density	0.17	0.26	1	
IP	0.48	0.65	0.10	1

From the master dataset the characteristics of the data was varied

1. The same CoV (35 %) for MOR and r^2 (0.5) between IP and MOR but with three different mean values of MOR (30, 45 and 60 MPa)
2. The same mean value of MOR (45 MPa) and r^2 (0.5) between IP and MOR but with three different CoV (20, 35 and 50 %) for MOR
3. The same mean value of MOR (45 MPa) and CoV (35 %) for MOR but with four different r^2 (0.1, 0.3, 0.5 and 0.7) between IP and MOR.

The first condition represents a difference between batches in mean strength of the timber. The second represents a difference in Coefficient of Variation, or normalized standard deviation, and the third condition represents different correlations, r^2 values, between IP and the grade determining properties (MOR, MOE and density), or how well the IP can predict the property.

4.3 Description of the program

The K-, Y- and Z-coefficients for standard C-grades according to EN14081 are preset in the parameter file, which can be appended with user defined classes. The IP-values are user changeable to be able to simulate grading with different settings to maximize the yield. The calculations follow the standard EN 14081-3:2005.

It is possible to select a whole data file or a subset thereof. The selected data can be sorted according to any column before calculation. By this is it possible to simulate pre-sorting of boards or logs. If there are log-values in the data file, *e.g*. density or frequency, it is possible to sort by that column and select boards from only the wanted logs. There is also a "random number" column, which can be re-randomized and resorted to simulate a new random appearance of the boards.

An overview of the selected data are shown in two graphs, see Figure 1. The upper diagram shows MOE as a function of MOR. Other parameters, such as IP logs, Density, Width and Thickness can be compared to MOE and can be displayed in the upper diagram. The lower diagram shows MOE and MOR of boards compared to the IP-values of the boards. The min and max values of IP, MOE, MOR and Density of the boards are shown in the table on top of the page. By this it is possible to get an overview of the dataset.

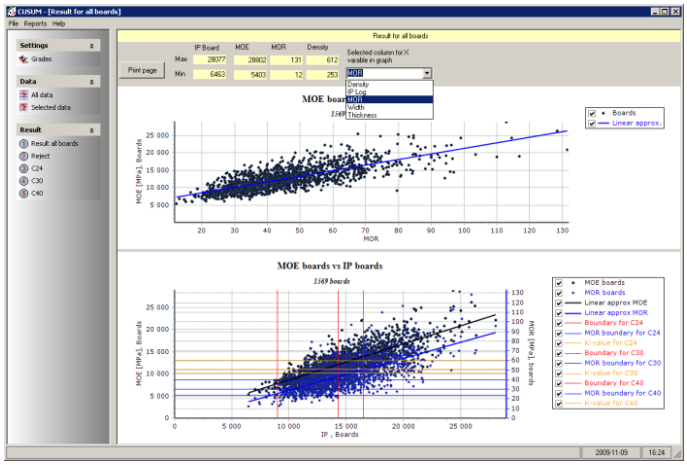

Figure 1: An overview of the selected data is shown in two graphs. The min and max values of IP, MOE, MOR and Density of the boards are also shown.

When clicking the wanted grade, in the left part of the screen, two new diagrams are displayed, see Figure 2. The first diagram is showing the output control chart, according to the standard, with each group's cusum values for MOR and MOE and the Y-values plotted. The second diagram shows a graph where each board's MOR and MOE are plotted as function of IP.

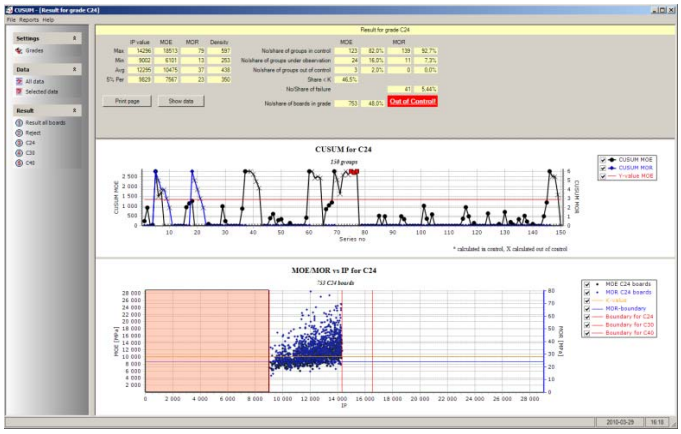

Figure 2: Output control chart and each board's MOR and MOE plotted as function of IP.

The need for "Setting adjustment" are noted as red squares due to low MOE for groups no 75 - 77.

In this screen are also shown the numerical values of min, max, average and 5 % percentile of IP, MOE, MOR and Density; the number of boards in the grade and the share of all selected boards; the number and share of groups "In control", "Under observation" and "Out of control" for MOE and MOR; the share of boards below the K-value and the number and share of boards that failed proof loading.

If some group is "Under observation", "Setting adjustment" or "Out of control", it is easy to see in the graph. Groups on or above the Y-line in the upper diagram are "Under observation". In case of "Under observation", the "Out of control" chart calculation scheme is used, which is marked by x:s instead of dots in the graph. After the first "Under observation" cases in the test run the production came back "In control". Starting with group no 69 in Figure 2 too many boards had low MOE, so a "Setting adjustment" occurred and the groups are marked red in the chart. In the standard it is possible to have six groups "Under observation", then six groups with "Setting adjustment". If the production has not come back "In control" after the six "Under observation" groups and six "Setting adjustment" groups, the production is "Out of control". In production, an adjustment of settings is possible or necessary after a "Setting adjustment" occurrence, but as the program in this case calculates on "historical" data, no adjustments are made. The calculation continues and more "Setting adjustment" groups can exist. This is an exception for this program and is not according to the standard, where production must stop and adjustments have to be done.

To see the sensitivity of the IP-value boundaries, a randomization was performed, to get the boards in a new order. As seen in Figure 3 more "Setting adjustment" (red squares) occurs. This implies that the IP-boundaries are too generous, and a change of settings is needed.

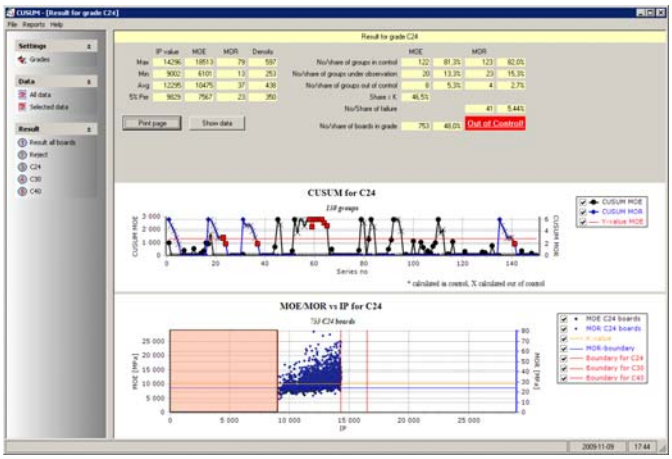

Figure 3: The grading with new randomised order made more boards to be "Out of control".

The IP-boundary between reject and C24 is changed from 9,000 to 11,500 to get fewer boards with low IP-values in grade C24. The result can be seen in Figure 4.

In Figure 4 some groups are still "Under observation" but none is in "Setting adjustment" or "Out of control". A lot less groups are "Under observation", which could mean that the margin to "Out of control" is larger than before.

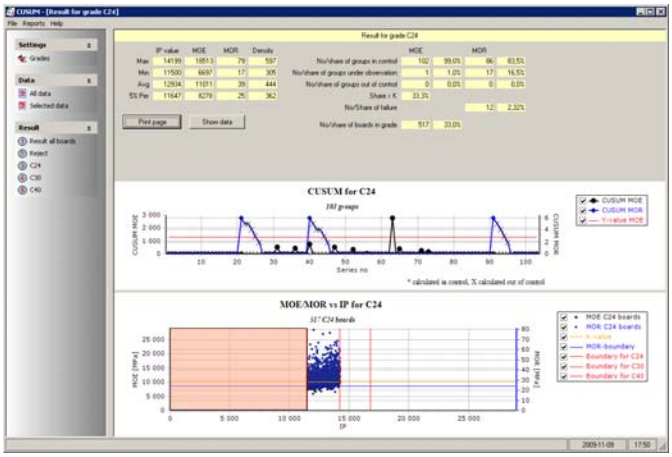

Figure 4: The distance to "Out of control" is larger than before.

To be on the safe side new simulations shall be performed with re-randomised order. This change of IP-value boundary makes the C24 grade more on the safe side, as fewer "bad" boards (low IP) appear in C24. The economic evaluation for the saw mill to make is to examine the cost of production stop compared to yield. The economics is out of the scope of this analysis program.

5 Results when using the program

5.1 Sensitivity and risk for production stop

The main issue for the cusum method is to verify that the graded material fulfils the requirements for the specified grade and to serve as a tool for optimizing the settings for a particular sawmill. It must therefore be able to identify settings that are too low (or too high). The method is evaluated from the data-set described in section 4.2.

A reference setting for an imagined class C30 was determined as the IP-value where the requirements for MOR and MOE are fulfilled. For the whole sample of 20,000 specimens this was satisfied for an IP value of 10,900. The cusum-program was then used ten times with the setting 10,900 as well as with two lower settings (-5 % and -10 %) and one higher setting (+5 %) to produce C30. The yield and the occasions extra testing in "Under observation" were required as well as the number of occasions when production has to be stopped was evaluated.

The relation between setting and the number of times "Under observation" (times when extra testing is required) is plotted in Figure 5. It seems to be a linear relation, at least for settings close to the theoretically correct one.

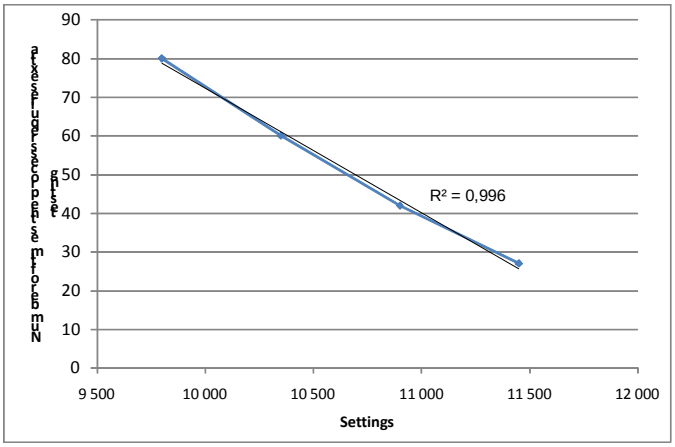

Figure 5: The relation between setting and required extra control (mean of 10 simulations)

The effect of the linear relation is that there is not a specific limit for an optimized setting. The producer can, based on economic decisions, choose a balance between yield and testing costs. It seems that the risk for a production stop and a major change of the settings is low, even with settings more than 10 % lower than the theoretically correct settings. With one production shift per day the example represents a production time of almost 10 years. During this time only one production stop can be expected, even with settings that are 10 % lower than the theoretically correct settings.

5.2 Quality shift

The control procedure must be sensitive to changes of the incoming material to be graded. This can be simulated with the computer generated data-sets with different mean values or with different coefficient of variation. It can be noted that although the change of quality is large, it is not possible to detect short periods of low incoming quality with the present procedure. It is not likely that a shift in incoming raw material quality is detected unless it is covering a period over several weeks.

5.3 Pre-grading of logs

Previous work has shown great advantages in production control when pre-grading logs [4]. In order to see the yield difference and the difference in risk of production stops when having pre-graded logs, a test with simulated log grading is performed. A log grading with a density meter is simulated, so the 5 % boards with the lowest density are removed from the data set. The IP is set to 10,900.

The pre-graded data-set was compared with the reference data-set, and it can be seen that the yield of the pre-graded data-set (19,000 boards) has improved by 1 %. The number of times when additional testing is required has decreased from 5 to less than 4 per year. The yield in grade C30 from the total 20,000 boards in the dataset has decreased from 90 % to 85 % with the gain of having fewer occasions with extra testing.

6 Discussion

From the analysis made on the cusum-procedure it can be seen that the procedure is able to identify productions where too low (or too high) settings are used. However, it is a coarse method and the consequence for the company using too low settings is mainly an increased number of pieces to be tested and increased costs due to that. The linear increase of required amount of tests with less conservative settings makes the determination of settings into an economical decision for the producer; a lower setting increases the yield but also the number of tests that can be expected. The risk of a stop of the production with downgraded material and restart of the verification process of the cusum is small. The high number of possibilities to come back into control, 12 groups to be tested, minimises this risk even with settings much lower than the required.

The method is not suitable for determination of short time variations of the quality of the incoming material. Due to coarseness of the method, the large amount of testing required before any actions are necessary a shift of quality can last for weeks before it is discovered.

Pre-grading of logs can increase the reliability of the settings and decrease the number of extra tests required. However the producer has to pay with a lower total yield. The effect is very similar to the effect of an increase of the setting but since it is made at the beginning of the production chain it may still be profitable.

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