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Machine Grading of Lumber

Practical Concerns For Lumber Producers

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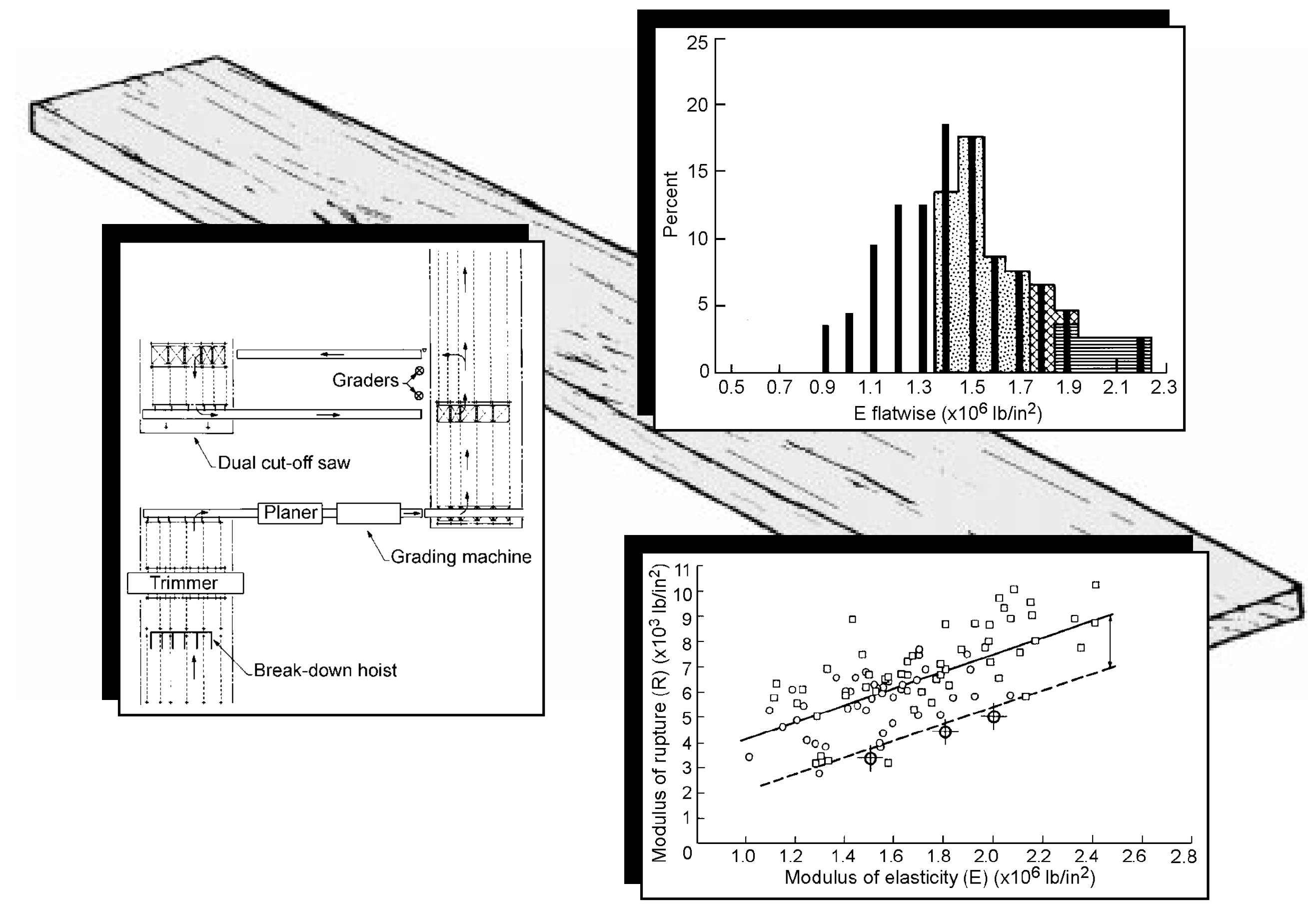

Abstract

Machine lumber grading has been applied in commercial operations in North America since 1963, and research has shown that machine grading can improve the efficient use of wood. However, industry has been reluctant to apply research findings without clear evidence that the change from visual to machine grading will be a profitable one. For instance, mill managers need guidelines on machine grading. This report seeks to document such guidelines so that lumber mills can determine the feasibility of machine grading for their products. The first part of this report discusses the principles of using machine grading to assign properties. In the second part, the methods of machine-graded lumber yield assessment are described by an industry specialist. The final part discusses mill mechanical analysis and cost analysis.

Keywords: Mechanical grading, yield studies, regulatory acceptance

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This edition replaces the 1977 General Technical Report FPL–GTR–7, *Machine Stress Rating—Practical Concerns for Lumber Producers,* by William Galligan, Delos V. Snodgrass, and Gerald W. Crow.

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Acknowledgments

Special recognition is given to William L. Galligan, Delos V. Snodgrass, and Gerald W. Crow, authors of the original FPL–GTR–7, which was published in 1977. In the 2000 version of this report, the primary authors of the sections entitled "Assessment of Production Potential" and "Mill Application" are Delos Snodgrass of Simpson Timber Company and Gerald Crow of Crow Engineering Company, respectively. The material in these sections and that in the Introduction was presented in part at the Annual Meeting of the Forest Products Research Society in Portland, Oregon, 1975.

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Preface

Machine grading is a reality, but it is surrounded by a maze of truths, half-truths, and plain misunderstanding. The economic significance of all this will be settled in the marketplace, but many questions have underlying technical answers—and such answers are widely spread among specialists.

The Forest Products Laboratory (FPL) naturally tries to keep abreast of these and other developments that affect the utilization of wood. This particular publication resulted from specific requests for such information. The Northeastern Lumber Manufacturers Association (NELMA) and the Forest Service State & Private Forestry unit at Portsmouth, New Hampshire, asked if the FPL could summarize information on the principles of machine grading and furnish some idea of costs. Some of this information was prepared for them and published in the NELMA Proceedings. This publication led to further requests and resulted in the work reported here.

An overview of this magnitude is difficult to prepare, and it must be used with care in a particular situation. For instance, cost estimates would probably not be totally accurate at any single mill. Yield estimates are general estimates, and they become outdated quickly. However, these numbers do provide some general guidance and furnish a basis for a mill to begin to examine its own situation critically. The procedures and data outlined here provide an analytical tool for utilization extension specialists to aid in mill yield analysis.

This report is an update of general technical report FPL–GTR–7, which has been used steadily since its initial publication in 1977. The contents, including the general background to grading, the principles of assessing grade yield, and the diagrams of mill lumber flow, remain accurate and useful. However, technology has brought about changes in the industry, such as new grading machines, qualification and subsequent marketing of new grades of lumber, expansion of the number of allowable properties assigned through the machine sorting process, and the development of E-rating for laminating lumber.

To reflect the broadening use of grading with machines in North America, the original title of GTR–7 has been generalized to Machine Grading of Lumber to acknowledge that machines are used for E-rating as well as “stress” grading. In addition, the text is limited to dimension lumber; the application of machine-grading principles to non-dimension material, such as veneer and timbers, is beyond the scope of this report. In the same manner, the use of mechanical grading devices outside of North America is not addressed.

When the original GTR–7 was introduced, grading machines had only been in use for about 14 years and major areas of North America had no installations. Now, machines are installed in most areas and are supervised by many agencies approved under the American Lumber Standard (ALS) or under the regulations of the American National Standards Institute for laminating lumber under ANSI/AITC A190.1. Consequently, the list of machine installations and their operating characteristics has been replaced by a compilation of machines that currently operate under the ALS for grading dimension lumber and machines that are being used to identify laminating lumber under ANSI/AITC A190.1.

Over the years, a number of descriptive terms have been used in commercial machine grading. To make the necessary additions and modifications to update GTR–7 as simply as possible without rewriting the report, the terms mechanical grading and machine stress rating (MSR) were replaced with the generic terms machine grading and machine stress grading. Both terms apply to the process of lumber grading in North America that is both manual and mechanical. The term stress grading continues to be used to signify the generic process whereby allowable strength properties are assigned to the lumber grade. The term E-rating is introduced for laminating grades sorted by machine for stiffness. The term MSR is currently specific to one version of machine stress grading.

The SI conversion factors for the English (inch–pound) units of measurement used in this publication are shown in the following table:

SI conversion factors

English unit	Conversion factor	SI unit
inch (in.)	25.4	millimeters (mm)
foot (ft)	0.3048	meter (m)
square foot (ft^2)	0.093	square meter (m^2)
cubic foot (ft^3)	0.028	cubic meter (m^3)
pound (lb) mass	0.454	kilogram (kg)
pound/cubic foot (lb/ft^3)	16.0	kilogram/cubic meter (kg/m^3)
pound/square inch (lb/in^2)	6.895	kilopascal (kPa)
acre	0.4047	hectare (ha)

Machine Grading of Lumber

Practical Concerns For Lumber Producers

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Introduction

Stress grading for structural lumber is not new. Although visual stress grading has been used for 80 years, the concept of stress grading with the assistance of a machine has been applied commercially in only the past three decades. Most structural lumber in North America is still visually graded, but the volume of mechanically graded lumber is increasing.

Practical concerns affect the decision to install machine grading systems. For instance, a manager of a medium-size sawmill may be interested in any profit potential available through machine grading but may lack the information necessary to evaluate its effect on the mill operation. Because competitors may be using machine grading, the manager continues to search for ways to update the sawmill while producing a profit and maintaining or improving the quality of the product. Or a manager may decide to apply a combination of grading technologies to make specific products. In this case, machine grading may be considered as a supplement to visual grading. This publication explains the basic system of machine grading, provides methods for assessing feasibility at the mill level, and lists sources for further information on grading, siting, and machine availability.

History of Visual Stress Grading

Stress grades were developed for structural lumber because designers wanted safe and economical working stresses. The USDA Forest Service, Forest Products Laboratory, published a set of basic grading rules with assigned stress values in 1923. These stress grades, designed for only the better lumber cut from a tree, were used essentially unchanged for more than 20 years.

World War II brought dramatic changes in the visual grading system, with the initial influence being a temporary increase in design stresses. The U.S. Army employed an 85% increase in design stresses. After the war, some of the temporary stress increases were made permanent. At the same time, a growing demand for timber placed pressure on the grading system and other changes were made to use the timber resource more efficiently. The most dramatic recent change was the American Lumber Standard (ALS) PS 20–70, which came into effect in September 1970 (ALS 1970). This product standard incorporated several features, including the assignment of green and dry sizes to accommodate shrinkage of green lumber in place. Under PS 20–70, a National Grading Rule was written that prescribed uniform grading features for the same dimension grades of all species.

The next major change in procedures for the visual grading system occurred in 1991 with the adoption of new design stresses based on testing of full-sized pieces. Sampling and analysis were conducted on major species of dimension lumber in the United States and Canada. In support of full-size lumber testing, two ASTM standards were written: ASTM D1990, Standard Practice for Establishing Allowable Properties for Visually Graded Dimension Lumber From In-Grade Tests of Full-Size Specimens, and ASTM D4761, Standard Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material (ASTM 1996). Although overall changes in allowable property assignment through the new procedures were not major, design stresses for certain species and grades changed significantly.

The visual grading system has served our Nation well for many years. The strong point of this system is that it permits the production of vast quantities of structural materials that are compatible with a major construction need: light-frame housing. A point of concern is the wide variety of grade–species combinations employed by the system.

In the 1950s, technological and economic pressures introduced a second and somewhat competing system—machine grading. Although the balance of this document deals primarily with machine grading, note that the application of machine grading has always been measured and considered against a background of visual grading practice and tradition.

History of Machine Grading

Machine Stress Grading

Machine stress grading was founded on principles that had been known for more than 20 years. The major efforts that brought about a feasible industrial method were accomplished by Potlatch Forests, Inc. (Lewiston, Idaho), the Western Pine Association (Portland, Oregon), the

Commonwealth Scientific and Industrial Research Organization (Melbourne, Australia), and the Timber Research Unit of the Council for Scientific and Industrial Research in South Africa. Each of these organizations produced a commercial grading machine in the early years of machine stress grading (1960–1970), using essentially the same principles of the relationship between lumber stiffness and bending strength, which permit a grading system less oriented to species than is the visual grading system.

Although grading machines were enthusiastically received, their operation was hampered by misunderstanding about the marketing of machine-stress-graded lumber and the lack of uniform quality control procedures. For example, some producers found that a wide range of moisture content and/or dimension adversely affected the efficiency of the process; poor mill operation and machine grading could not exist side by side. Similarly, the technical understanding of machine grading operations was not uniform. Early tests on machine-stress-graded lumber suggested the need for change. Consequently, quality-control procedures were formalized and became the responsibility of grading agencies in the same manner as visual grading was regulated. In addition, visual restrictions on edge-knot size were placed on lumber.

Mills that adopted machine stress grading did so primarily because of producer interest, rather than consumer interest. As a result, some early grades were not entirely relevant to marketing needs. This resulted in gradual changes in grade descriptions as the technology evolved. The advent of machine grading inspired research worldwide, in both the fundamental principles of machine grading and their extension to grading criteria and commercial application.

Early users of grading machines assumed that consumers would enthusiastically accept machine graded lumber. This assumption was quickly shown to be wrong. Market experience suggests that the ability of a lumber producer to determine the mill's capability for machine grading should be based on an understanding of (1) the basic philosophy of machine stress grading, (2) ways to market lumber for specific end uses, and (3) the potential grading economics of the raw material. Today, U.S. companies active in machine grading have generally developed a sophisticated appreciation for their potential as producers of structural lumber, both visually and mechanically graded.

By 1996, machine-stress-grading systems had achieved a commercially important level of usage in North America. Approximately 1 billion board feet of machine-stress-graded lumber were produced in 1996, the majority in 2 by 4 and 2 by 6 lumber for metal plate trusses (MSR Lumber Producers Council 1996).[1] A major barrier to growth of machine stress grading stems from its commercial competition with visual grading. The two systems, which function differently, may "disagree" in how the lumber should be sorted, thus implying that some graded material may not be suitable for the intended end use. Also, no mill grading system completely dependent upon machine grading principles has yet been demonstrated to be feasible. Therefore, the producer interested in understanding the options of existing grading processes must compare the yield obtained by visually grading alone to the potential yield from coexisting machine and visual systems.

The past 20 years of mechanical grading have highlighted that the process coexists with visual grading primarily because of favorable grade yield to the producing mill. Although the use of mechanical grading is accompanied by design advantages for some end products, the process is principally employed to develop grades not attainable by visual grading or to develop increased yields of grades similar to visual grades. This is especially true in grading "secondary" species, such as Hem–Fir and Spruce–Pine–Fir, from which highly competitive grades can be derived.

E-Rated Grading

In the late 1970s, a second form of mechanically graded lumber was introduced to supply lumber to the laminating industry. The E-rated grades are an alternative to visual grades for laminating lumber because they are based on mechanical grading to achieve a long-span, flatwise measurement of modulus of elasticity (MOE). Visually limiting criteria for edge characteristics are similar to the criteria for machine-stress-rated lumber. The E-rated grades, although they are obtained mechanically with many of the same devices used for machine stress grading, are not "stress" grades because they do not require destructive tests for qualification of strength properties, only nondestructive tests to verify MOE. In addition, this modulus is measured flatwise, whereas the modulus assigned to stress-rated grades is measured edgewise. Because they are destined for lumber laminations in a beam, E-rated grades must meet all the criteria for glued-laminated lumber (such as dimensional tolerances and moisture content), criteria that are usually more restrictive than those applied to framing lumber. Nevertheless, the similarity of E-rated and stress-rated grades has been some cause for confusion, particularly for those not familiar with one or the other of these processes. Two issues are critical to the producer:

1. Machine-stress-rated and E-rated lumber can be qualified and produced simultaneously. It is possible to maintain quality control over both systems.

2. In production and marketing, it is important to separate the identity of the grades and grading systems because they differ in descriptions, yields, qualification, and quality control requirements.

[1]The terms "2 by 4" and "2 by 6" refer to nominal 2- by 4-in. (standard 38- by 89-mm) and nominal 2- by 6-in. (standard 38- by 140-mm) lumber.

Theory and Practice of Machine Grading

Machine Stress Grading

All stress grading systems are based on the use of predictors to estimate strength properties. In visual grading, the size of visual defects such as knots is used to predict strength. In machine grading in North America, the combination of edge-knot size and lumber stiffness has been the traditional predictor. In the early 1990s, a second system was introduced in commercial production, one that uses density as a predictor instead of stiffness (Ziegler 1997). In this report, stiffness (E) will be used to illustrate the mechanically measured predictor variable; however, the illustrations are intended to be generic and also apply to the use of density as a predictor. Furthermore, the reader should note that differences in predictive efficiency, and consequently product yield, may vary by choice of predictor as well as by choice of grading equipment and the product requirements.

All North American mechanical grading systems employ some form of visual "override," a visual appraisal of specified characteristics that affect piece strength and stiffness, as well as limitations to end use performance such as warp and wane. Most often these are stated as limitations on characteristics falling at the edges of the piece. This visual override system started in machine stress rating stated as the fraction of the cross section and was made part of the grade description. In this report, the term visual quality level (VQL) signifies the traditional limitations on edge characteristics and other criteria such as wane, warp, and skip.

In addition to the limitations on edge characteristics, many supervisory grading agencies require a limitation on characteristics such as knots at the ends of pieces or other areas not tested by the mechanical device. Because these rules vary by agency, they will not be included in example discussions of grade yield in this publication. Nevertheless, these characteristics, if limited, can affect yield, and the reader is advised to consult with the agency regarding the potential limitations.

The relationship between the predictor and the mechanical property of interest is commonly shown by a statistical technique known as a regression. Figure 1 illustrates the use of a regression to show the effect of variability in data on the accuracy of prediction. The tighter the data group around the regression line, the lower the variability and the better the prediction of strength. Figure 2 shows the use of E as a single predictor of bending strength with lumber data. In this figure, a lower tolerance limit is used rather than a regression line. Only a small proportion of the pieces fall below the tolerance line; design values are set from this point on the basis of safety factors and other adjustments. Research continues to seek more efficient predictors of strength properties. As noted in the previous text, the two nondestructive predictors currently used in commercial equipment are E and density.

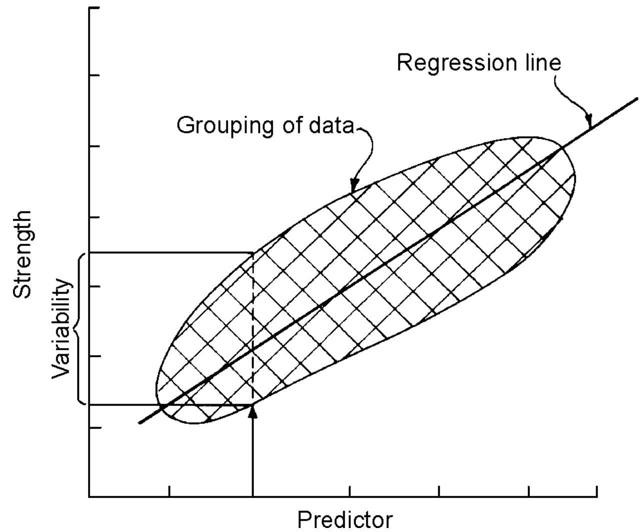


Figure 1—Prediction of strength by regression analysis.

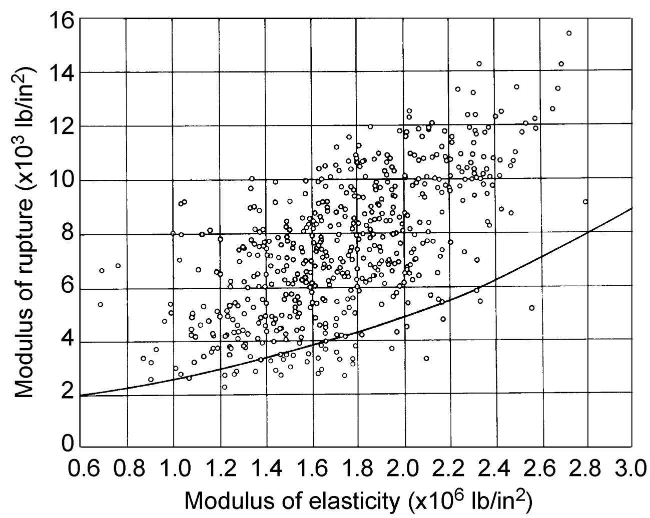


Figure 2—Typical relationship between strength predictor, MOE, and strength. The tolerance limit assures that about 95% of the data will fall above the line.

Some characteristics of machine stress grades are better understood if contrasted with the characteristics of the more familiar visual grading system. One characteristic is the variety of design values available with the two grading systems.

For visual grading, the National Grading Rule permits different design property levels for the same visual grade, as a function of species. For example, Table 1 compares bending stress and E values of a series of machine grades with some typical 2 by 4 visual grades. Design values, E and F_b, assigned to machine grades (circa 2000) are shown in the left-hand column. Visual grades meeting the same allowable values in accordance with the visual stress-grading process

Table 1—Comparison of allowable bending properties of machine and visual grades of 2 by 4 lumber at 15% moisture content

Machine stress grade (F_b, E)	Visual grade F_b level[a]				Visual grade E level[a]			
	S. Pine	Douglas Fir–Larch	Hem–Fir	Spruce–Pine–Fir	S. Pine	Douglas Fir–Larch	Hem–Fir	Spruce–Pine–Fir
2850–2.3	SS							
2700–2.2								
2550–2.1								
2400–2.0								
2250–1.9		SS				SS		
2100–1.8			SS		SS			
1950–1.7					No. 1	No. 1		
1850–1.6	No. 1			SS	No. 2	No. 2	SS	
1650–1.5							No. 1	SS
1500–1.4	No. 2	No. 1			No. 3	No. 3	No. 2	No.1, No. 2
1350–1.3		No. 2	No. 1	No.1, No. 2				
1200–1.2			No. 2				No. 3	No. 3
900–1.0								
<900–1.0	No. 3	No. 3	No. 3	No. 3				

[a]SS is Select Structural.

are placed in the corresponding positions in the table. Although for any one visual grade (No. 1, for example) the visual grade descriptions are the same for all species (same knot size, same slope-of-grain requirements, etc.), different design values are assigned by species. This visual grading procedure results in a wide number of grades in the marketplace. For example, more than 80 different design values are available in visual grades of 2 by 4 lumber.

Table 1 also illustrates that a direct correspondence between machine grade properties and visual grade properties is not possible without knowing the species of the visual grade. This table is for illustrative purposes only; a producer interested in evaluating the potential of machine grading as opposed to visual grading should create a table with the current grades of interest.

In contrast with the visual grading system, there are fewer machine stress grades. This results because these grades can have a uniform set of design values in bending, tension, and compression across species instead of varying by species as do the visual grades. While Table 1 illustrates the variety of design values that can result from the species influence in the visual grades, the leftmost column of Table 1 and the table of design values from the 1976 WWPA grading rule (Fig. 3) both illustrate the contrast, a smaller set of common values across species in the machine grades (WWPA 1976). In the last 15 years of machine grading, however, a more varied array of machine grades has developed, often because qualification by test has illustrated more potential yield to a producer for the particular timber source, linked to the market objective. As a result, some of the initial simplicity of the machine grading system has diminished because the flexibility of the system has allowed more grade/property combinations in an effort to optimize the resource.

Because machine stress grading sorts lumber into grades using a mechanically measurable predictor, the result is grades that are less variable in the predictor (density or E) compared to similar visual grades (Galligan and Snodgrass 1970). To illustrate this comparison, Figure 4 shows the distribution of E in Standard grade western hemlock. Visual grading in different mills can result in different stiffness distributions within the same species (Galligan and Snodgrass 1970) (Fig. 5). By contrast, the machine stress grades tend to be more restricted in E distribution, as shown in the distribution data reported for one mill (Fig. 6) (Galligan and Snodgrass 1970). The variability in E and the difference in E distribution between mills are essential elements in exploring the grading options of a mill. This complex problem requires a deliberate assessment technique, as will be discussed in detail in subsequent sections of this report. Furthermore, the co-existence of machine grading systems with different predictors may result in several levels of variability in market grades. These issues warrant discussion with supervisory grading agencies.

Allowable property assignments for machine grades are presented in Appendix A, along with nomenclature and performance criteria. Selection criteria for strength test samples are described in Appendix B, and matrix evaluation of machine grades is presented in Appendix C.

MACHINE STRESS-RATED LUMBER
2" AND LESS IN THICKNESS
2" AND WIDER
Recommended Design Values
in Pounds Per Square Inch

"f--E" Clasification	Extreme Fiber Stress in Bending "Fb" (1) Single	Repetitive	Modulus of Elasticity E	Tension Parallel to Grain "Ft"	Compression Parallel to Grain "Fc"
*1200f – 1 2E	1200	1400	1 200 000	600	950
1500f – 1 4 E	1500	1750	1 400 000	900	1200
1650f – 1 5 E	1650	1900	1 500 000	1020	1320
1800f – 1 6 E	1800	2050	1 600 000	1175	1450
2100f – 1 8 E	2100	2400	1 800 000	1575	1700
2400f – 2 0 E	2400	2750	2 000 000	1925	1925
2700f – 2 2 E	2700	3100	2 200 000	2150	2150
3000f – 2 4 E	3000	3450	2 400 000	2400	2400
3300f – 2 6 E	3300	3800	2 600 000	2650	2650

The above listed f-E classifications are those that have customarily been used for trussed rafters and other engineered 2x4 construction. The classifications listed below are designed to provide MOE levels with corresponding lower Fb requirements especially for joist use. Although the tables are separated primarily on the basis of rafter and joist use any f-E classification may be ordered which meets the requirement of design.

900f – 1 0 E	900	1050	1 000 000	350	725
900f – 1 2 E	900	1050	1 200 000	350	725
1200f – 1 5 E	1200	1400	1 500 000	600	950
1350f – 1 8 E	1350	1550	1 800 000	750	1075
1800f – 2 1 E	1800	2050	2 100 000	1175	1450

	Douglas Fir & Larch	Hem-Fir	Pine (2)	Engelmann Spruce–Alpine Fir	Cedar (3)	Western Hemlock
Compression Perpendicular to Grain "Fc ⊥" (DRY)	385	245	190	195	265	280
Horizontal Shear "Fv" (DRY)	95	75	70	70	75	90

(1) The tabulated Extreme Fiber in Bending values "Fb" are applicable to lumber loaded on edge. When loaded flatwise, these values may be increased by multiplying by the following factors:

Nominal Width (In.)	3"	4"	6"	8"	10"	12"	14"
Factor	1.06	1.10	1.15	1.19	1.22	1.25	1.28

(2) Idaho White, Lodgepole, Ponderosa or Sugar Pine.
(3) Incense or Western Red Cedar.

Figure 3—Common property values across species in machine grades as revised in the 1976 WWPA grading rule (WWPA 1976).

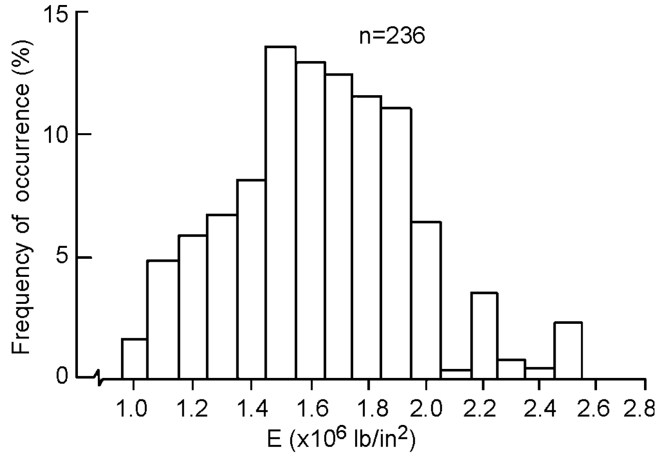


Figure 4—Distribution of E in sample of Standard grade western hemlock.

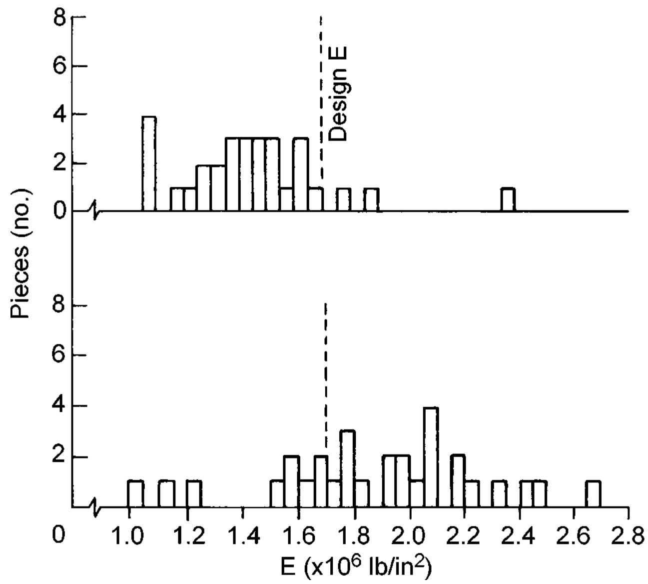


Figure 5—Example of differences in E in samples of same grade of lumber graded at two lumber mills.

E-Rated Grading

Laminating lumber must meet the requirements of ANSI/AITC A190.1 (ANSI 1992). This standard and related reference documents require knot size and frequency and E data by grade. This information is an essential input that determines the assigned design properties of the laminated beam. For both visually and mechanically graded lamina, supervisory laminating associations obtain the knot and modulus data by survey of graded lumber. E-rated laminating lumber is distinguished from visually graded laminating lumber by specific requirements for quality control of both the mean and variability of the grade E. These criteria are listed in the basic reference, AITC 117 Manufacturing Annex D (AITC 1993).

Mechanical devices that measure the E value of each piece are usually well suited for grading E-rated lumber. A principal technical issue for a manufacturer is the relationship between the stiffness measurement made by the machine compared to the specification, which is the long-span, flatwise E as defined in ASTM D3737 (ASTM 1996). Some devices measure and sort lumber based on deflection over a short span (in this sense, a length shorter than the length of the piece of lumber); others measure over a short span but integrate the results over the entire length of the piece; still other devices make one measurement over the entire length of the piece. As a consequence, both the manner in which the data are obtained and the manner in which they are analyzed and reported by the device influence the relationship between the machine data, the specification, and the grade yield. For this reason, the output of the device is always

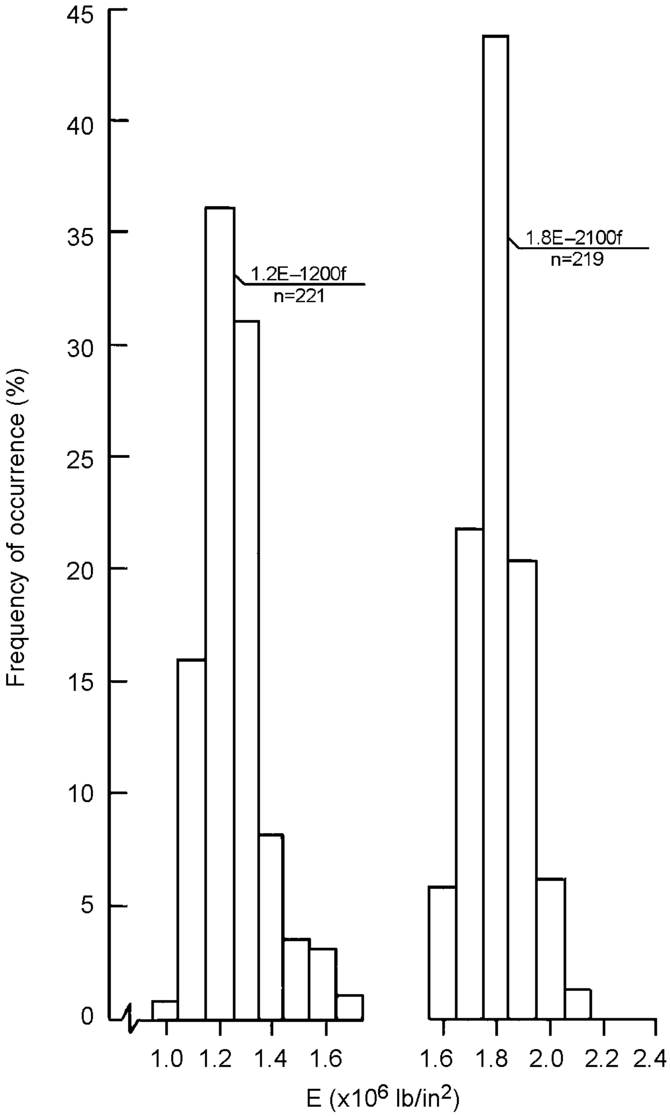


Figure 6—Variability in MOE in two typical machine stress grades.

calibrated by static test against the performance specification of AITC 117 Manufacturing by the supervisory agency. However, the relationship between the device measurement and the E specification is generally very robust for E-rating, because most mechanical devices for E-rating deflect the lumber in the same flatwise orientation as that of the E-rated specification.

A limited number of E-rated grades are commonly produced; the number and properties vary by species. This limitation is determined by the composition required for the laminated beams of current commercial interest and the subsequent allowable design values that can be produced with this E-rated lumber. As a consequence, E-rated grades are generally not commodity products and are produced after careful marketing discussions with the customers, the laminated beam fabricators.

Implementation of Machine Grading

Machine Stress Grading

Most lumber that is machine stress graded in the United States is graded under the auspices of the ALS (ALS 1970). Thus, machine-stress-graded lumber has the same legal and procedural backing as do the ALS visual grades. Like visual grades, machine grades are assigned properties. As with all ALS grades, a machine grade requires an official grade stamp, which must state that the lumber was machine graded, to distinguish it from visually graded lumber. Under the ALS system, quality control and certification procedures are required. New or modified grades may be developed to meet market needs as long as visual criteria are met as limited by agency rules.

The implementation of a machine grading process involves all members of the marketing chain, from the lumber mill to the final distributor. The responsibilities that are particularly important for machine stress grades are discussed in the sections on certification and quality control under Mill Application.

Before a machine stress grading operation is implemented, the supervisory grading agency requires certain certification requirements. The certification procedure is based on sampling and destructive testing of lumber to establish both strength and stiffness. The results permit the grading agency to specify the proper machine operation. Some agencies require tests for both tensile and bending strength in this initial appraisal. Others qualify the machine grading operation on one strength property and corroborate the other with additional testing.

The operation and maintenance of the machine and traditional visual supervision take place on company premises. Daily quality control is required in which lumber samples are tested to verify that the process, both mechanical and visual, meets agency criteria. The grading agency provides technical support and supervision through this quality control program.

The machine stress grades produced must be acceptable to engineers, code authorities, and regulatory agencies. To achieve that acceptance, most companies rely to a great extent on their ability to meet the ALS requirements for production and quality control and on that representation by the grading agency or lumber association.

As is traditional with visually grade lumber, the grading agency provides the technical and practical data that suggest the capabilities of machine stress grades for marketing use. These data are reported in design references such as the *National Design Specification for Wood Construction* (AF&PA 1997), as well as in the grading rules. In addition, the grading agency fields questions on specific design applications; it works with authorities in the code and regulatory areas to secure acceptance of property data; it may seek variances in existing practice to make the grading process compatible with the needs of the mills; and it often anticipates technical or interpretive questions from engineers and scientists in design or application positions.

E-Rated Lumber

The E-rated grades are produced to meet the criteria of American National Standards Institute ANSI/AITC A190.1, the *American National Standard for Wood Products—Structural Glued Laminated Timber* (ANSI 1992). The lumber may also may be graded under the supervision of ALS-approved grading agencies. Since the E-rated grades are not commodity grades for widespread consumption, their qualification is generally the result of consultation among the supervisory agency, the lumber producer, and one or more potential customers (laminators). The agency supervises qualification and stipulates quality control methodology. The number of grades of interest are limited; each grade must link directly into a laminated beam layup. When the need for the grade is established, the grade must also have associated data on knots, as noted previously. Consequently, to promote E-rated lumber, a producer either produces grades that meet currently demonstrated needs or becomes familiar with the intricacies of layup design in order to promote appropriate use of new grades.

The E-rated grades are designated by the E level and by the size of the permitted edge characteristic. An example is 2.3E–Y6. The term 2.3E denotes the mean E of the grade, and the number 6 denotes edge knots or other characteristics limited to 1/6 of the cross section in this grade. Criteria are set for both the mean E and the 5% tolerance limit of E.

The laminating industry has also adopted the use of mechanical grading in conjunction with existing visual grades which, in effect, produces a third system of grading. In this usage, a criterion is placed on a visual grade that precludes any lumber below a low E limit. In effect, this practice removes the lower portion of the tail of the E distribution of the visual grade. The other characteristics of the grade, such as knots and mean E, may be assumed to be the same as though the E cut-off were not used. The criteria for a mean E and a 5% tolerance limit on E (as applied for E-rated grades) do not apply. Consequently, the resulting grade remains a "visual" grade and is not governed by the E-rating criteria under ANSI/AITC A190.1 or the layup rules of ASTM D3737 for E-rated lumber (ANSI 1992, ASTM 1996).

Current Machine Grading Operations

Domestic Operations

The number of machine grading operations in the United States remained rather constant from the mid-1960s to about 1973, when the number of installations increased, accompanied by shifts to modernization and increased production capacity. From 1990 to 1996, the production of machine stress grades increased 45%, to more than a billion (10^9) board feet (MSR Lumber Producers Council 1996). Production figures for E-rated lumber, which are not available, would augment that total.

The primary market for machine-stress-rated lumber is the structural light-framing grades. The highest strength grades were originally used for specialty trusses such as those manufactured by the Trus-Joist Corporation (Boise, Idaho); more commonly these grades are now used for high capacity metal plate trusses. An additional specialty market for these higher grades is tension-test qualified lumber for the tension laminations of laminated beams. "Medium"-level structural light-framing grades, such as 1650f and 1800f, are generally sold for metal plate trusses designed for the housing and light industrial markets. Lower grades, such as 1350f and 1450f, meet the requirements for shorter span roof trusses and also serve as substitutes for visual light-framing grades.

Although the machine grading process allows all possible combinations of species and grade, contingent upon passing qualification and meeting quality control criteria, the practical fact is that yield of the grade determines the market potential. For example, experience has shown that the higher grades, such as 2400f-2.0E, can be qualified by test from the western true firs; however, the volume generated from these species may preclude specific mills from developing market quantities. Later sections of this report explore yield estimation.

As noted previously, the domestic market for E-rated laminating lumber is not commodity driven; rather, E-rated laminating lumber is most often sold directly to the laminator. These grades have been most successful in species such as Hem–Fir where it is more feasible to produce a beam of 2400f design value with E-rated lumber than to produce a beam with the same capacity from visually graded lumber. The limited market in the United States for laminated beams in other than Douglas Fir or Southern Pine has not supported large quantities of E-rated lumber in the "secondary" species. Consequently, the choice to produce E-rated material for the domestic market is highly specific to the mill and customer base.

An alternative use for E-rated lumber in laminating is as a substitute for visual laminating grades. Based on analysis of beam requirements using principles of ASTM D3737 (ASTM 1996), certain E-rated grades have been granted "equivalency" with visual grades in beam layups otherwise designated for visual grades. Both the buyer and seller stand to benefit: the yield of E-rated lumber may be advantageous to the lumber producer and the laminator may use E-rated lumber in a "substitution" mode.

Foreign Operations and Markets

Machine grading originated in Australia to fill the need for more accurate stresses for lumber used in trusses made from Monterey pine from New Zealand. The Australian laboratory developed one of the first commercial stress-grading machines. Stress-grading machines have also been developed in South Africa, Europe, and Japan.

The emergence of a new market for machine-graded lumber in Japan is an example of research and development germane to local needs. In 1996, Japan adopted a new laminating standard that emphasized lumber machine graded and qualified by test for E and strength. This standard provided beneficial beam layups when lumber was machine graded. Although market strength has varied, in 1997 at least eight laminators in the United States were using machine grading for this export market.

Assessment of Production Potential

A company that is contemplating machine grading must evaluate the impact of such a process on the mill and in the marketplace. This evaluation requires knowledge of not only the quantity of machine-graded lumber of various grades that the available lumber resource will produce, but also the grade content and quantity of the residual lumber that will not be machine graded. The economic evaluation depends on the total product mix being produced at a mill, its market value, and the cost of production. Machine grading can affect the economic return favorably or unfavorably, depending on the specific production and marketing circumstances. The difficulty of assessing the production potential has been a long-standing problem. In 1970, R. J. Hoyle, Jr., presented some yield estimates for machine stress grades made in the early 1960s (Hoyle 1970). Hoyle's report was a unique analysis of production potential because it dealt frankly with production and grading realities. Readers will find the yield comparisons between species and geographic regions of particular interest. Much of what is reported was based on data obtained early in the development of machine grades. The concept of visual restrictions as presently used was not included in the yield analyses. Consequently, the grades in the Hoyle paper are not synonymous with those in current use.

The following discussion of production potential is based on machine stress grading using stiffness measurement for all examples. The Hoyle process is updated to reflect visual restrictions, market potential, and quality control concepts. This discussion does not address E-rated lumber in any depth. The general concepts of yield measurement and comparison with visual grades apply to both systems as well as to machine-stress-rating systems based on measurements other than stiffness, such as density. In general, stress rating system analysis is more complex than that required for E-rating because of the need for strength assessment in stress rating systems. The only general caution directed to the reader interested in E-rating is to carefully consider the visual, size, and moisture requirements unique to laminating. These factors alone have a significant effect on yield assessment.

Note: It is important to reemphasize that a stereotypical format for grade descriptions, including visual restrictions, is used in the following example. If the grades considered are those generated with a density-profiling system in which the edge characteristics are included in the machine output, or if the visual restrictions are in some other way accommodated by grading agency procedure, it is critical that the user of this yield study technique take the necessary steps in sampling and analysis to reflect those choices. The same general comment applies to applications where several grading systems may be interlocked on the grading chain and/or the grades being developed do not fit the stereotype used in this report.

This report is limited to estimating the change in product mix if machine stress grading were introduced into a mill currently producing dimension lumber and grading by the traditional visual process. This report is also limited to meeting one strength testing criterion (bending strength). If the grading system or the agency requires qualification in more than one strength criterion (see App. A), the estimation method shown here may need to be conducted for more properties, emphasizing again that this is for estimating purposes and the aid of the agency is essential.

The method of estimation is demonstrated by an example from experience. This example is limited to 2-by-4 Hem–Fir and to estimating the production capability of this lumber resource with respect to three of the higher machine grades. The basic method or procedure of estimating is applicable to lumber resources of different sizes and species, as well as other machine grades. The results of such an estimate may be significantly different from the example. The estimating method consists of the practical interpretation of appropriate statistics, sampling, lumber production, grading rules, lumber marketing, grading machine behavior, and mechanical properties of lumber. No in-depth treatment of any of these fields of endeavor is intended; this example only illustrates a basic analysis technique that can be broadly applied.

It is also important to acknowledge the timelessness of this type of analysis—it was developed in the 1970s—and the fact that, because of the date of the development, computer spreadsheets were not used in the examples. However, since that time, users of GTR–7 have routinely converted the concepts to spreadsheets. Moreover, the illustrations use grade rules, assigned design values, nomenclature, and references that were current in the United States in the mid-1970s. The principles of the section can be applied to different grading systems, products, and applications. Consequently, in applying the principles described in this section, the user must take steps to ensure that design values and associated nomenclature are current and appropriate for the intended application.

Definition of Terms

Unfamiliar terms often obscure rather than explain. Consider, for example, "grading lumber" as opposed to "sorting lumber by grade." The term grading lumber, which is almost universally used in the lumber industry, seems to imply that the lumber mill has some prerogative in assigning structural or use values to lumber. This prerogative in fact rests with those organized bodies responsible for the development of grading rules. The mill enters the lumber grading process after the rules have been established; it retains only the responsibility for sorting lumber in accord with these rules. Of course, the mill does have options within the rules, and it is these options that will be discussed here.

The terms machine grading or machine stress rating can be confusing because they imply that the grading or sorting by grade will be done only by a machine. In fact, some machine grading uses both people and machines. This combined approach to machine grading sorts lumber into grades by applying certain visual rules similar to some of those used for visual stress grading, while the lumber is simultaneously sorted by machine into categories or grades that contain certain mechanically measured characteristics. Both aspects of the system—characteristics subject to visual inspection and those measured by machine—limit the grade level for which a piece is qualified. Thus, the grade into which a piece is sorted will be the lowest grade level as determined by the person or the machine.

Machine stress grades are designated by the recommended design values for the grade in extreme fiber stress in bending F_b and modulus of elasticity E or by a name, such as M–23, to which the design values are associated. For example, the grade designation 1650f–1.5E means a machine grade with an allowable F_b of 1,650 lb/in^2 and a design E of 1.5×10^6 lb/in^2; M–23 identifies a MEL grade with an allowable F_b of 2,400 lb/in^2 and a design E of 1.8×10^6 lb/in^2. See Appendix A for more discussion.

The E-rated grades are designated only with the allowable design E value (for example, 1.5E) and the visual edge characteristic level maintained in that grade (for example, 1/4). Consequently, a typical grademark for an E-rated grade would be 1.5E–1/4. No strength values are assigned E-rated grades.

Slight differences in grade combinations, grademarks, and grademarking procedures exist between grading agencies. For uniformity throughout this report, the species, grades, and procedures of the Western Wood Products Association (WWPA) form the basis for all illustrations (WWPA 1974). If a similar survey is conducted, it is important to apply the current rules of the appropriate agency.

The table from the WWPA publication on special product rules (Fig. 3) shows the 14 machine grades contained in the grading rules, their names, and the recommended design values (WWPA 1976). Again, note that this illustration was prepared in 1979; grades are always subject to change. The current grades applicable to the study should be substituted if the following illustration is followed.

No one mill can produce all of these grades at the same time. Five grades would probably be a practical maximum for a mill, as limited by production and lumber resource capabilities. The market constraints may reduce this number even further. The analysis that is used must consider all alternative choices and limiting constraints.

As noted, some machine grading systems have a human-based visual grading component. Since that is the basis for this illustrative method and to simplify the following discussion, the concept of visual quality level (VQL) and the terms VQL–1, VQL–2, VQL–3, and VQL–4 are introduced to indicate the visual characteristics of any given piece of machine-graded lumber where a combined visual and mechanical system is involved. The size of allowable edge characteristics is different for each of the four VQLs contained in the grading rules and is specified as a fraction of the cross section. These VQLs correspond, in turn, to F_b levels for which a piece of lumber is qualified under these rules (assuming E levels are also satisfied). Table 2 shows this relationship. The edge characteristic restrictions for machine stress grades are very nearly equal to those applied to certain visual stress grades, as shown in Table 3. The method of defining and controlling the edge characteristic may vary by grading agency.

For checks, shake, skips, splits, wane, and warp, there is one level of acceptance for most machine-graded lumber under the ALS. This level is the one applied to No. 2 or Standard grade in the ALS Joist and Plank, Structural Light Framing, or Light Framing rules. In recent years, a modification to the visual rules has permitted No. 3 level visual characteristics, such as wane and skip, for machine stress grades of 900f and lower. Furthermore, many agencies apply additional visual restrictions to areas of the piece not mechanically examined, such as areas near the ends that are not tested by some machines.

Table 2—Definition of machine stress grading visual quality levels relative to maximum edge knot size and allowable bending stress[a]

Visual quality level	Maximum edge knot size as fraction of cross section	Range of accepted F_b (lb/in^2)
VQL–1	1/6	≤3,300
VQL–2	1/4	≤2,050
VQL–3	1/3	≤1,450
VQL–4	1/2	≤900

[a]Grading Agency rules; ALS Standard PS–20–70.
Note: Other visual characteristics, such as checks and splits, are equal to that of No. 2 or standard visual grades.

Table 3—Approximate equivalent edge knot sizes for machine and visual stress grades

Machine stress grades		Visual stress grades	
VQL	Edge knot as fraction of net cross section	Structural Light Framing or Joist and Plank grade	Edge knot as fraction of net cross section[a]
1	1/6	Select Structural	1/6+
2	1/4	No. 1	1/4+
3	1/3	No. 2	1/3+
4	1/2	No. 3	1/2

[a]Plus sign signifies that knot size, as computed as a fraction of actual cross section, is slightly larger than the fraction shown.

The grading criteria for visual grades, on the other hand, are based on sizes of *both* "edge" and "elsewhere" visual characteristics such as knots, checks, shake, skips, wane, warp, pitch and pitch streaks and pockets, slope of grain, stain, and unsound wood. Furthermore, these characteristics change by visual grade.

Further comparison of the VQL requirements for machine-graded lumber and the characteristics of visually graded lumber will be useful to identify visual lumber grades that will supply the material for the grades of interest. For simplicity in these comparisons and in the illustrations of grade yield that follow, the additional visual restrictions for untested areas and the No. 3 allowance for lower grades are not considered. A user may wish to add these guidelines as well as those illustrated here if a study warrants that detail.

Even if the user of these illustrations is estimating yields and performance of a system that does not have the person-based visual component for stress grade assignment, the impact of these features should not be ignored. One system, for example, makes algorithm adjustments for strength-affecting features at the edge of the piece. Consequently, the sampling of grades and analysis of results relating to occurrence of edge features remains an important issue even though the "person component" is reflected in the mechanical sensing and interpretation. Assistance of the machinery manufacturer and the grading agency is important in such an analysis.

The maximum allowable edge knot sizes for various sizes and grades of lumber in both visual and machine stress grades are shown in Table 4. This table demonstrates that, for example, the edge knot requirements for Select Structural are similar to those for VQL–1, but Select Structural permits a slightly larger edge knot. Thus, Select Structural 2 by 3 lumber (1/2 in. maximum edge knot) will be sorted into both VQL–1 (7/16 in. maximum edge knot) and VQL–2 (5/8 in. maximum edge knot) classes by the visual grading requirements of the rules. Estimation of the potential of machine grades from existing visual stress grades must take these differences into account to provide appropriate data.

For categorizing quality criteria, one approach is to group by "structural quality," which affects the strength of a piece of lumber primarily through the relative knot size; another is by "appearance quality," which limits the usefulness or market acceptance of a piece by other criteria. Thus, a piece of lumber may have high strength and stiffness, giving it a structural quality equivalent to Select Structural, but because of warp or skip the piece will be properly assigned to No. 3 or Utility grade for marketing. In the machine-stress-grading or sorting system the structural quality criterion is emphasized more than it is in the visual grades because, as noted, the appearance quality limitations are equivalent to those for visual grade No. 2 for all structural quality (E) levels. Using this simplified approach of simultaneously exercising judgment with respect to two criteria to sort lumber by grade, we can develop an understanding of relationships that exist between visually stress-graded lumber and machine-stress-graded lumber. This understanding is useful in identifying the portion of the visually graded lumber that can be machine stress graded.

One way to visualize the effect of sorting by two criteria is to construct a chart that divides a field vertically by one criterion and horizontally by the other. This has been done in Tables 5 to 7 for visual stress grade, VQL, and machine stress grade categories, respectively.

Tables 5 and 6 show how acceptability for both visual and machine stress grades is limited with respect to edge knots and to characteristics other than knots. These figures can be directly compared because they contain the same lumber. In a sense, only the names of the grades are different. Although the lines drawn by the rules are not quite as precise as indicated, some general conclusions can be drawn with respect to the question, What portions of the visual grades of lumber are qualified or not qualified for machine stress grading?

1. All 2-in. dimension No. 2, No. 1, and Select Structural grades can be machine graded.
2. All 2-in. dimension Standard and Construction (Std & Btr) grades can be machine graded except for that portion of Standard with edge knots larger than half the cross section (Tables 4 and 6).
3. Only that portion of No. 3 grade limited by knot size (for example, not by No. 3 wane, etc.) can be machine graded (Tables 5 and 6).
4. No Utility[2] or Economy lumber is qualified for machine grading (Tables 3, 5, and 6).

[2]Utility grade is not demonstrated in the charts, but by definition it contains knots or other visual characteristics larger than those contained in Standard grade. Therefore, much utility grade is ineligible for inclusion in the machine grade lumber resource item (visual grade, size, species) currently being produced.

Table 4—Maximum allowable edge knot sizes (in inches) in visual and machine stress grades[a]

Size	Machine VQL–1	Visual SS	Machine VQL–2	Visual No. 1	Machine VQL–3	Visual No. 2	Visual Cons.	Machine VQL–4	Visual No. 3	Visual Std.	Visual Utility	Visual Econ.
2 by 3	7/16	1/2	5/8	3/4	13/16	7/8	1-1/4	1-1/4	1-1/4	1-1/2	2	Unlimited
2 by 4	9/16	3/4	7/8	1	1-3/16	1/1/4	1-1/2	1-3/4	1-3/4	2	2-1/2	—
2 by 6	15/16	1-1/8	1-3/8	1-1/2	1-13/16	1-7/8	—	2-3/4	2-3/4	—	—	—
2 by 8	1-3/16	1-1/2	1-13/16	2	2-7/16	2-1/2	—	3-5/8	3-1/2	—	—	—
2 by 10	1-9/16	1-7/8	2-5/16	2-1/2	3-1/16	3-1/4	—	4-5/8	4-1/2	—	—	—
2 by 12	1-7/8	2-1/4	2-13/16	3	3-3/4	3-3/4	—	5-5/8	5-1/2	—	—	—

[a]WPPA (1974). Edge knot size is expressed to the nearest 1/16 in. Cons. is Construction; Econ., Economy; Std., Standard.

Table 5—Relationship between knot sorting criteria and sorting criteria other than knots for visual grades[a]

Other sorting criteria[b]		Visual grade knot sorting criteria				
	Visual grade	Select Structural	No. 1	No. 2	No. 3	Economy
	SS	SS	1	2	3	E
	No. 1	1	1	2	3	E
	No. 2	2	2	2	3	E
	No. 3	3	3	3	3	E
	Economy	E	E	E	E	E

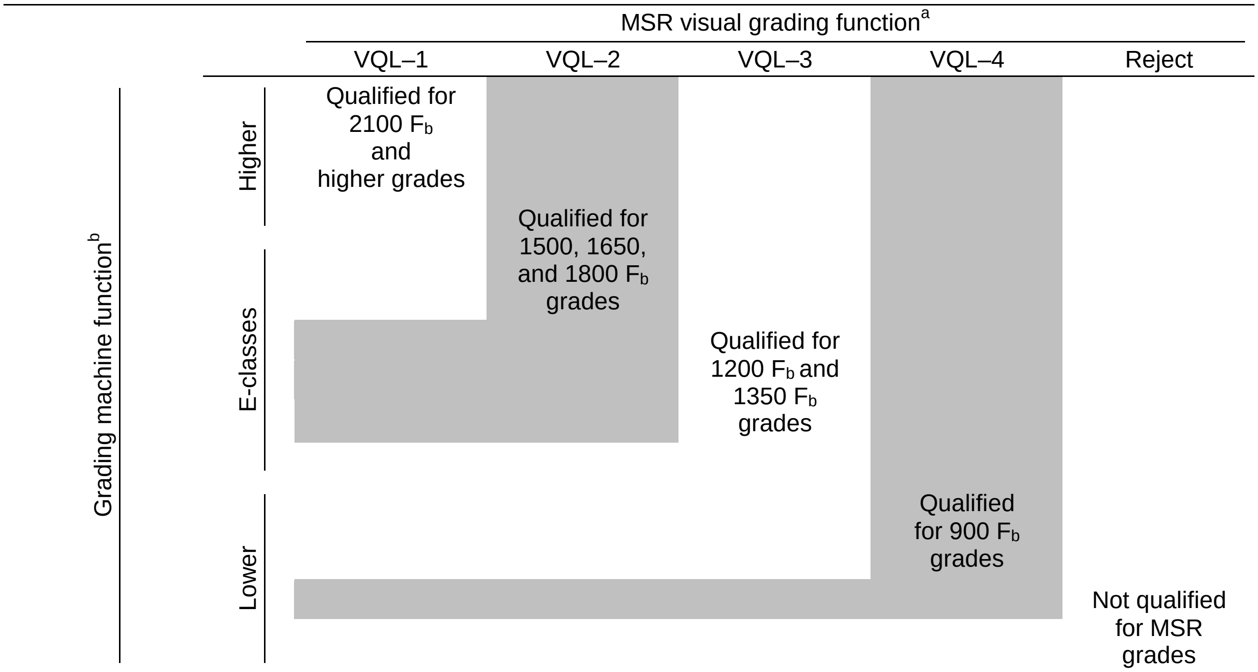
[a]Shading designates portion of visual grades not eligible for machine grading because of visual characteristics.
[b]Checks, shake, skips, wane, warp, pitch, pockets, slope of grain, stain, and unsound wood.

Table 6—Relationship between VQL knot sorting criteria and other VQL sorting criteria relative to visual grade criteria[a]

VQL sorting criteria other than knots[b]		VQL knot sorting criterion and approximate lumber grade				
		1/6	1/4	1/3	1/2	>1/2
	Visual grade	SS	No. 1	No. 2	No. 3	Economy
	SS	VQL–1	VQL–2	VQL–3	VQL–4	NA
	No. 1	VQL–1	VQL–2	VQL–3	VQL–4	NA
	No. 2	VQL–1	VQL–2	VQL–3	VQL–4	NA
	No. 3	NA	NA	NA	NA	NA
	Economy	NA	NA	NA	NA	NA

[a]Shading designates areas in which visual grade characteristics are not permitted in machine-stress-rated grades.
[b]Based on relative visual grades.

Table 7—Interaction of visual grading function (by grader) and grading machine function (by machine) in sorting lumber by machine-stress-rating grade rules



[a]Identify pieces qualified for MSR grades by visual quality level.
[b]Identify pieces qualified for MSR grades by E-classes, by range of acceptable stiffness.

Conclusions 3 and 4 are not exactly true because of differences in handling of unsound wood or decay in the two different grading systems. However, the frequency of exceptions to these conclusions is often so low that the Utility and Economy grades can be assumed to contain no suitable lumber for the purpose of the initial assessment of the potential of a mill for machine grading production.

The interaction between grader and machine in sorting lumber into the machine grades is portrayed in general in Table 7. This is a schematic of Table 2 combined with E-class criteria. Groups of possible grades, as opposed to single grades, are contained in the divisions shown.

A useful piece of information conveyed by Tables 5 to 7 is that any machine grade will contain lumber of any No. 2, No. 1, or Select Structural grades of the visual grading system. Also, machine grades of the 900fb level will also include some lumber from the No. 3 visual grade.

The previous statements can be reworked into a series of important questions:

- If mill X were to change from its current visually graded product line, what grades could it produce?
- How much of each grade could it produce?
- How much of each visual grade would be included in each machine grade?
- How much would be left over?

One method of obtaining this desired estimate of machine grade alternatives and their visual grade content can be outlined as follows:

1. Determine the volume (thousand board feet annual production) and content (visual grades, sizes, species) of the lumber resource being produced; for time unit, use annual production or some other accepted and relevant time scale.
2. For each item (visual grade, size, and species) of the lumber resource identified in step 1, determine the proportion (fraction or percentage) of each VQL contained within it.
3. For each lumber resource item, determine the distribution of E or proportion of various E levels contained within it.
4. Submit an appropriate sample to a breaking test to determine the strength–stiffness relationship of the particular lumber resource.

The recovery or yield estimates can then be made as follows:

1. Multiply the proportion recoverable as limited by E, by the proportion recoverable as limited by VQL (step 2), to obtain the proportion recoverable as machine-stress-graded lumber from the lumber resource item (each specific grade, size, and species identified in step 1) currently being produced.

2. Estimate the proportion recoverable as limited by E from the data in steps 3 and 4.

The recovery estimate is in fact complete at the end of step 1, but the data are split between the various lumber resource items (visual grade, size, species) and need to be summarized to show the total effect on the product mix. This can be done by reassembling by size and species to show not only the machine grade recovery estimates but also an estimate of the recovery by visual grade of the residual volume.

The final summary of the product mix can then be compared with the value of the current product mix. This comparison, along with factors including cost of installation, effect on total product line, and availability and cost of capital, can be used to decide whether to introduce machine grading in a mill.

Scope of Study

The first step in appraising the machine grade production potential of a mill is to establish the scope of the study to develop only those data that are pertinent to the machine grading issue. To determine the production potential for all machine grades from all possible sizes, grades, and species currently being produced in any given mill would generate more data than could possibly be used. Mill managers and marketing staff must appraise the objectives of their mills to set the limits of the investigation. In an actual case study, these limits were stated something like this:

> The market appears to demand primarily 2 by 4's and 2 by 6's in grades of 1650f–1.5E, 2100f–1.8E, and 2400f–2.0E in random-length assortments of 10 to 20 ft. The mill presently produces about 50% 2 by 4's, 20% 2 by 6's, and 30% other widths. Therefore, let us first investigate the production potential of our 2 by 4's with respect to 1650f–1.5E, 2100f–1.8E, and 2400f .0E grades. The results of this 2 by 4 study should suggest the overall feasibility of using machine grading, as well as provide guidance for further study with 2 by 6's and other widths and grades of lumber.

The demonstration in the next section accepts these limits and addresses the production potential of three machine stress grades from the 2 by 4 grades produced at a mill. The data shown are from an actual study made with this objective in mind.

Study Plan

Once the decision has been made to limit the investigation to 2 by 4's and three grades (1650f–1.5E, 2100f-1.8E, and 2400f-2.0E), the following questions can be addressed:

1. Which 2 by 4 grades shall be investigated?

2. What quantity of these grades are produced each year?

Review of the machine grading rules (Table 2 or 7) shows that the grades of interest fall in VQL–1 and VQL–2. The mill presently sorts 2 by 4's in accordance with a combination of the visual Structural Light Framing and Light Framing grades. The actual grade mix being marketed consists of Select Structural, Standard and Better, Utility, and Economy. The Standard and Better combination, of course, contains Standard and Construction grades of lumber.

Review of the conclusions from comparing the grading systems (Tables 4 to 6) shows that the desired machine stress grades come from only the Select Structural and Standard and Better grade mix.

The next step is to obtain actual data on grade yield. All needed data can be obtained at the mill, except for breaking strength; breaking strength data require an in-house testing device, the services of a testing laboratory, or the portable testing system of an agency. Obtaining grade yield data at the mill requires a form for recording the data (Fig. 7), a moisture meter, a static testing device for measuring E, and a qualified lumber grader.

The static tester is a simple mechanical device that applies a dead load to a piece of lumber placed flat on a 4-ft span. This or a similar device is an integral part of quality control systems for machines that use stiffness as the measured variable, and it can be built at modest cost from plans available through grading associations. A schematic of a static tester used by several grading agencies is shown in Figure 8.

A qualified lumber grader is a key person in obtaining the necessary data for evaluating grade recovery potential. The grader's job is to carefully appraise each piece to determine that it is of a given visual grade (and not of a higher or lower grade) and to determine its VQL for machine grading. If the grader is not accustomed to grading under the system for machine stress grades, sufficient time needs to be provided for orientation as well as possible consultation with grading association personnel. This acclimation to a different grading system should not be underestimated. Accuracy in grading reduces the errors inherent in making recovery estimates from relatively small samples. As noted, some machine grading systems may not have extensive visual "overrides" because of the manner of physical or mechanical measurement. Nevertheless, if the purpose is to examine grade yields, alternative grades, comparative systems, or resource variables, the grader assisting in sample selection and analysis should be well acquainted with all alternatives examined.

MSR Recovery Estimate —Data Sheet

Size 2×4 *Species* *Hem-Fir* Grade *Std & Btr*

Date 7/10/74 Comment *E. Jones, Grader*

WWPA Static Tester. Day Shift Production

	Visual Grade					M.C. %	MSR-VOL					E Defl.
Spec. No.	C	S					1	2	3	4	R	
81	X					7	X					.143
82	X							X				
83		X				13		X				.181
84	X					17			X			.147
85		X									X	
86	X						X					
87		X				12					X	.176
88	X					11		X				.163
89		X								X		
90		X				16			X			.113
91		X						X				
92	X						X					
93		X				9	X					.133
94	X					12			X			.182
95	X									X		
96		X								X		
97	X					10	X					.157

Figure 7—Simple form for recordkeeping.

To generate the data, follow these steps:

1. Select a number of pieces for inspection.
2. Record data for visual grade, moisture content, VQL, and static E for pieces in the sample.
3. Select a special sample from step 2 to determine the strength predictor (stiffness or density) relationship of the lumber resources.

Step 3 is most often performed in cooperation with the supervisory grading agency to assist in both testing and interpretation of data.

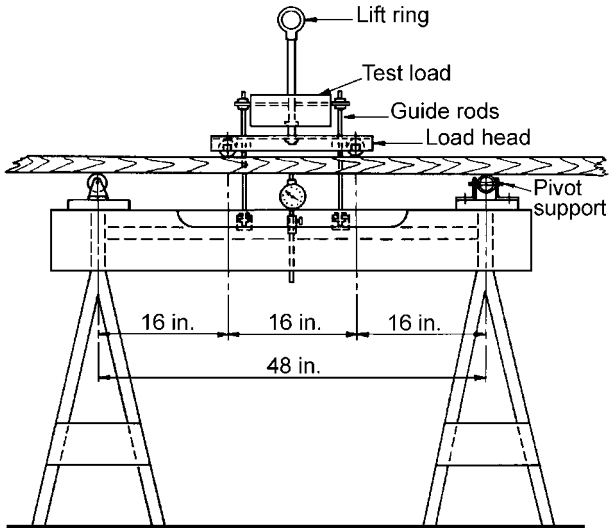


Figure 8—Static tester. This simple mechanical device applies a dead load to a piece of lumber placed flat on a 4-ft span.

The sample must represent the entire range of lumber to be machine graded—this is not simple to achieve. Various textbooks on sampling procedures may be followed, but the methods involved in sample collection may become cumbersome when applied to a sawmill operation. Consequently, some relaxation of strict rules of sampling may be in order. Experience suggests the following approximate methods can be applied with satisfactory results.

By using samples from current sawmill production, we hope to estimate what is likely to happen in the future. However, such an estimation rests on the assumption that the timber resource will remain relatively constant. In operating terms, as long as logs of the same grade quality from the same geographic area are processed, we can expect to obtain the same lumber product mix. To cut the time involved and to ensure a representative sample, select the sample at one time or from a lot of material that experienced mill personnel judge to represent the mill output.

The following example illustrates how to generate data for each visual grade, size, and species of interest. In this example, the data are generated for three grades of 2 by 4 lumber: Standard, Construction, and Select Structural.

1. Inspect 200 pieces of each grade to obtain the VQL data.
2. Inspect 75 to 100 pieces of each grade for moisture content and E. (Alternate pieces of the prior sample.)

To help eliminate possible bias in a non-representative lot, obtain these data from two lots of lumber that were produced at two distinct times. Inspect a 100-piece sample from each lot. Record VQL data on all pieces and record moisture content and E data on alternate pieces to obtain the desired quantity of data. If, on analysis, the results appear to be about the same for each lot, no additional data should be necessary. If the results appear quite different, obtain data from a third lot of lumber produced at a different time.
If one lot remains radically different from the other two, there may be an error of some sort or a non-representative lot. Consider discarding the suspect data and obtaining new information.

Appendix B provides general guidance for selecting a sample suitable for laboratory breaking tests. Such tests could determine the strength–stiffness relationships of any lumber resource. Making this selection, and subsequently processing the data, requires knowledge about the VQL and E of each piece sent to the laboratory. Therefore, each piece should be marked with its specimen number and sorted by VQL. Particular pieces are selected after reviewing the data generated for all pieces.

One area of critical interest that may require assistance from an agency is establishing the permissible levels of grade assignment when more than one grading system is in operation simultaneously. Two issues are involved: (1) the overlap of official rules concerning grading system and (2) the impact of more than one system on the validity of a sample for qualification or grade yield estimation.

The most important example of the first issue is the rule that precludes the production of any visual grade with an allowable fiber stress in bending that is higher than the fiber stress in bending of the lowest machine grade being graded from the same production. Consequently, the simultaneous operation of visual grading and machine grading may result in significant limits on the number of visual grades produced.

The second issue reflects the conflict that can occur when two or more systems are sorting with the same or very similar criteria. One example is when E-rated grades (selected on the basis of E and visual characteristics, including tight restrictions on surface quality) are being sorted simultaneously with machine stress grades that use the same sorting criteria with the exception of surface quality. Another example is the simultaneous grading of stress and non-stress grades. The grading agency and production personnel familiar with the process from log breakdown to the planer mill may be called upon to assure that the correct sampling process is used to truly represent production.

Gathering and Analysis of Data

Data Collection

In the example, the production schedule at the mill was such that 2 by 4's would be processed continuously for 3 to 4 days with an interval of 2 to 3 weeks between production runs. To obtain a representative sample from each of two production runs and to shorten the time required to obtain the samples, the following sample selection procedure was devised.

At 10- to 20-min intervals, a person was instructed to pull one piece of each grade of lumber desired—Select Structural, Construction, and Standard. The person was instructed to take the first piece of each grade as it came. Because the lumber was grademarked at this point, the person only had to read the mark to determine if a piece qualified for the sample. This process was continued until 100 pieces of each grade were collected from each of the two production runs of 2 by 4's.

These initial samples were selected by operating staff so that the collection could be conveniently conducted throughout the 3 to 4 days required and during both day and swing shifts. During each production run, 300 pieces were selected for the sample—100 pieces each of Select Structural, Construction, and Standard. The pieces were inspected and tested at the mill as follows:

1. Each piece was visually inspected by a senior grader to verify the grade shown on the grademark and determine the VQL.
2. Alternate pieces were checked for moisture content with a meter and for E by a static test device.
3. Records of all data were kept on a form (similar to Fig. 7). The static test for E and recordkeeping was done by an experienced technician hired specifically for the job. Only deflection was recorded on the data sheet, to eliminate the need for calculating an E value while obtaining the data.

To simplify selection of the sample to be sent to the laboratory, each piece was marked with its specimen number and set aside as sorted by VQL.

Data Analysis

Analysis of the VQL recovery potential from the various visual grades was made for each production run (Table 8). Utility grade was inspected in the first test run, although this was not necessary. Table 8 includes the Utility grade results to demonstrate that the potential for production of middle to high machine grades from Utility grade lumber is small indeed. The fraction recoverable from Utility grade was not included in the final analysis.

Comparison of data from the two test runs suggests the following observations:

1. VQL recovery from Select Structural grade was about the same in both runs.
2. VQL recovery from Standard and Construction grades appeared to be different in the two runs.

However, in this instance, the interest was in the recovery of VQL–1 and VQL–2 only. For these VQLs, the data indicate that the recovery potential is 100% of Select Structural, 43.2% to 53.7% of Construction, and 18.7% to 27.2% of Standard. Because the mill operators judged that the sample represented the logs they normally worked with and because the variations in VQL recovery potential could probably be bracketed by assuming ±5% when making economic estimates, it was decided to combine the results of the two tests (Table 9) and proceed.

At this point, another typical problem was encountered. The mill did not keep separate records for Construction and

Table 8—Recovery potential of two production runs of 2 by 4 machine-stress-graded VQL material

	Select Structural		Construction		Standard		Utility	
Run and VQL	No.	%	No.	%	No.	%	No.	%
First sample run								
VQL–1	110	96.5	31	28.7	14	13.6	0	0
VQL–2	4	3.5	27	25.0	14	13.6	3	2.6
VQL–3	0	0	20	18.5	26	25.2	1	0.9
VQL–4	0	0	30	27.8	39	37.9	0	0
Reject	0	0	0	0	10	9.7	111	96.5
Total	114	100	108	100	103	100	115	100
Moisture content	17.8%		16.4%		17.0%		17.3%	
Second sample run								
VQL–1	84	98.8	7	10.4	5	6.7		
VQL–2	1	1.2	22	32.8	9	12.0		
VQL–3	0	0	25	37.4	25	33.4		
VQL–4	0	0	13	19.4	19	25.3		
Reject	0	0	0	0	17	22.7		
Total	85	100	67	100	75	100		
Moisture content	14.4%		12.7%		13.4%			

Standard grades because this lumber was marketed in the Standard and Better grade mix. To complete the analysis as planned, it was necessary to determine the relative quantities of each grade that was being produced. To do this, the grademarks on samples of 200 consecutive pieces on the chain were tallied. This was repeated at approximately 20-min intervals.

The percentage of each visual grade observed was calculated on a cumulative basis for the entire lot and plotted (Fig. 9). Values were 6% for Select Structural, 55% for Construction, and 22% for Standard. From this base, recovery projections for machine stress grades were made.

Table 9—Recovery potential of combined runs for 2 by 4 machine-stress-graded VQL material

	Select Structural		Construction		Standard	
VQL	No.	%	No.	%	No.	%
VQL–1	194	9.5	38	21.7	19	10.7
VQL–2	5	2.5	49	28.0	23	12.9
VQL–3	0	0	45	25.7	51	28.7
VQL–4	0	0	43	24.6	58	32.5
Reject	0	0	0	0	27	15.2
Total	199	100	175	100	175	100

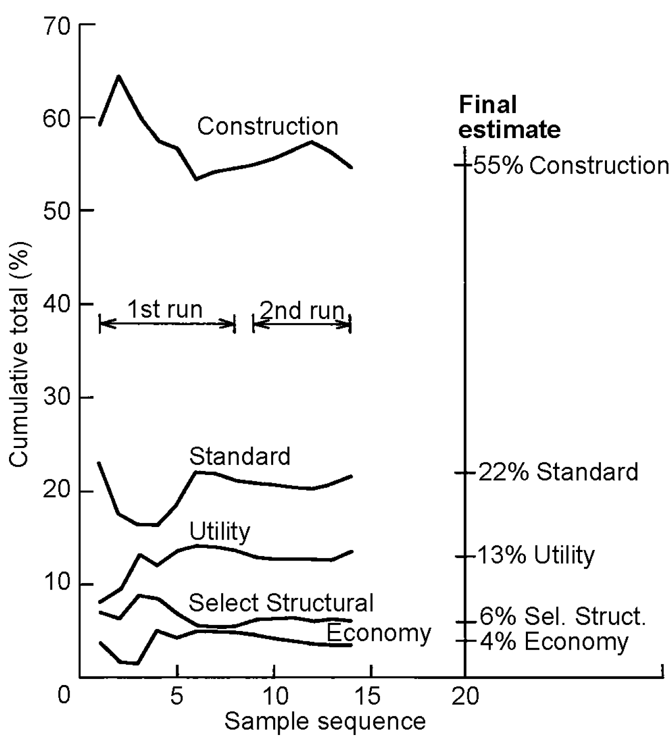


Figure 9—Production of each visual grade estimated by taking sequential 200-piece samples and plotting cumulative total of grades observed.

To determine what quantities of each stiffness category are present in the lumber, histograms of the percentage of each E class of 100,000 lb/in^2 can be made (Figs. 10 to 12). Such histograms can easily be constructed by hand or with the use of computer programs. In all instances, the average E observed was higher in the second sample than in the first. Moisture content was observed to be lower in the second sample and was assumed to be the cause of the higher

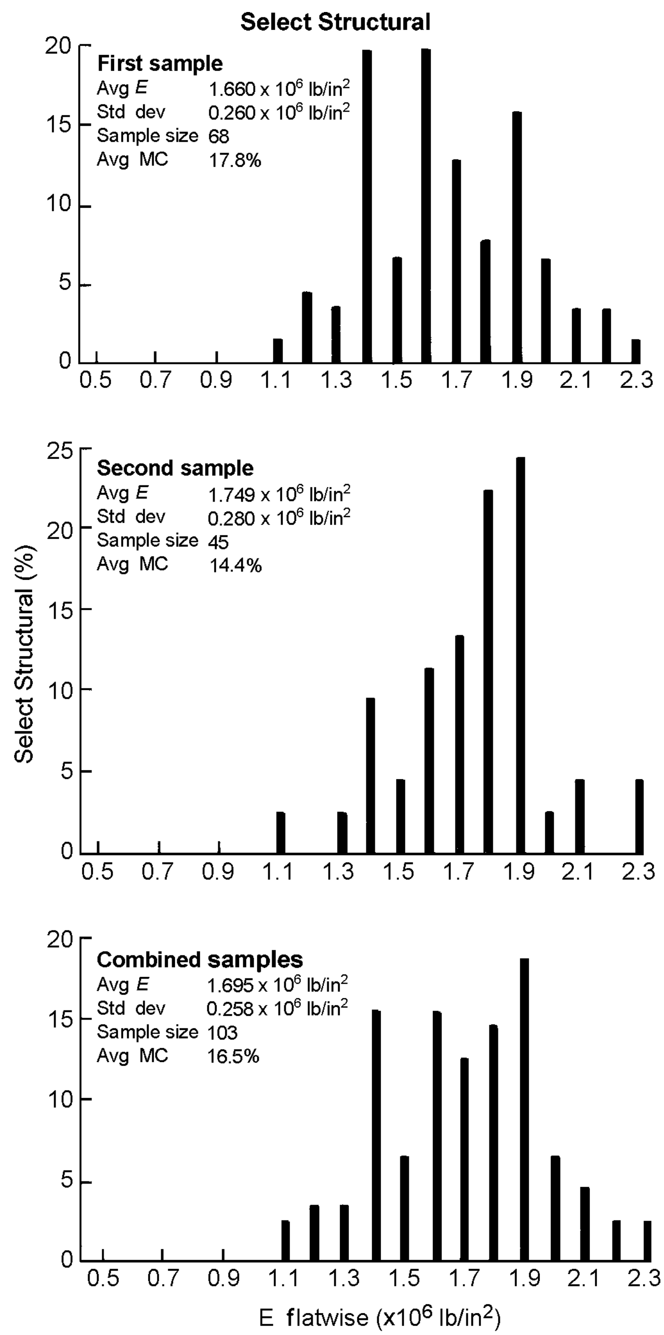


Figure 10—Flatwise E of 2 by 4 Select Structural lumber, as measured by static tester. Results for two individual samples and combined samples.

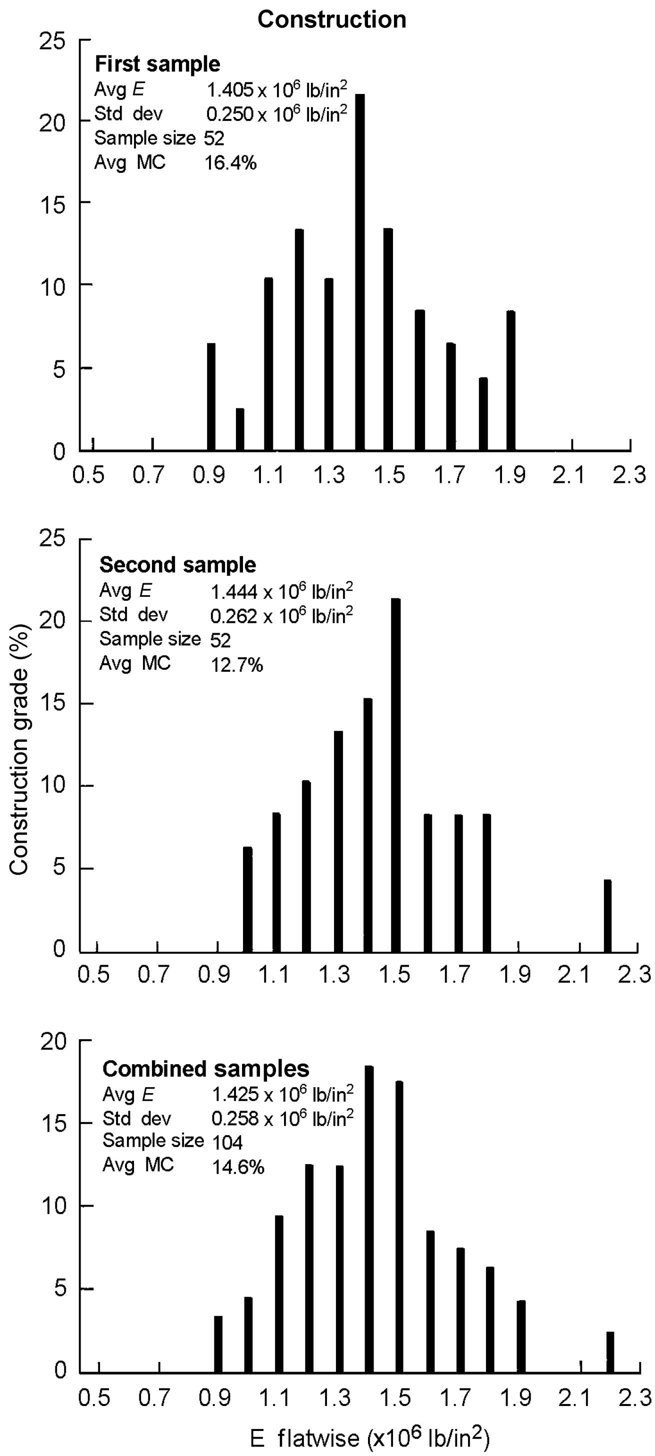


Figure 11—Flatwise E of 2 by 4 Construction grade lumber, as measured by static tester. Results for two individual samples and combined samples.

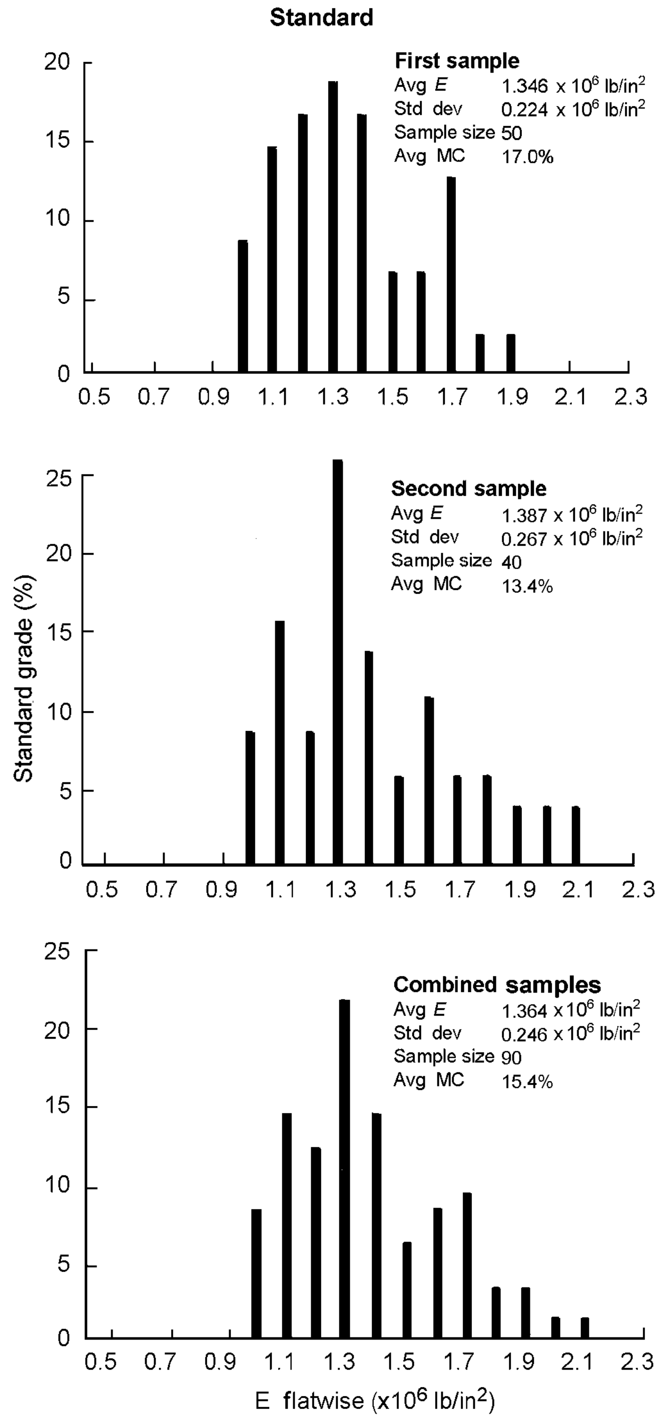


Figure 12—Flatwise E of 2 by 4 Standard grade lumber, as measured by static tester. Results for two individual samples and combined samples.

average E. This result underscores the need for good drying control to maintain recovery objectives when grading lumber by machine.

The final piece of information needed, the strength–stiffness relationship, was obtained by breaking the selected lumber sample in the laboratory and comparing the results.

Appendix B describes basic procedures for selecting samples. Grading agency supervision is desirable; agency procedures may be more specific than the general procedures described in Appendix B. Note that the sample sent to the laboratory for destructive testing came from material that had already been inspected. All the necessary data had already been recorded, and it was only necessary to identify the pieces wanted, sort them, and ship them to the laboratory.

The next task in the estimating process is to select a minimum average E value to be maintained by the production process. The actual minimum average E required of a machine stress grade will result from meeting three criteria: (1) The average E must be maintained at a level not lower than specified grade E; (2) the stiffness sorting criteria (average E and sometimes lowest within-piece E) must be maintained sufficiently high to satisfy the requirements for the specified strength properties of the grade; and (3) the near-minimum E of a lot must meet the requirements of the supervisory agency. The strength–stiffness data developed in the laboratory for this example are shown in Figure 13.

Note: If E-rated grades were to be qualified, criteria 1 and 3 would apply.

From these data, the minimum average E required of a grade for bending strength can be estimated. For this estimate, a line is drawn on the graph parallel to the regression line and 1.66 times the standard error below the regression line (Fig. 14). This line is an estimate of the 5% point estimate with respect to modulus of rupture (MOR) for the regression data. Again, although more sophisticated methods are available, this method has been found adequate for estimating purposes.

Next, find the point at which the 5% line is intersected by the MOR value equal to 2.1 by the grade F_b. From the graph, read the E value of this point and add l00,000 lb/in^2. This estimates the mean E value required for the grade in question. In Figure 14, the value $2.1 \times 1,650$ (MOR = 3,465) intersects with the 5% line at 1.42E; after adding 100,000 lb/in^2 (0.lE), an estimate of mean grade E for the 1650F_b grade will be 1.52. Note that this is slightly greater than the required 1.50E grade. Because both the conditions of grade E and grade F_b must be met simultaneously, use the larger of the two values when estimating recovery. In the example here, the average E required for each grade of interest is only slightly greater than grade E in each case:

Grade	Average E from graph
1650f–1.5E	1.52
2100f–1.8E	1.82
2400f–2.OE	2.01

This method of estimating the average E required was developed as a rule of thumb from monitoring breaking tests of the grade output of an operating machine grading system over a period of several years. It is both judgmental and empirical in nature, and further experience may improve the method.

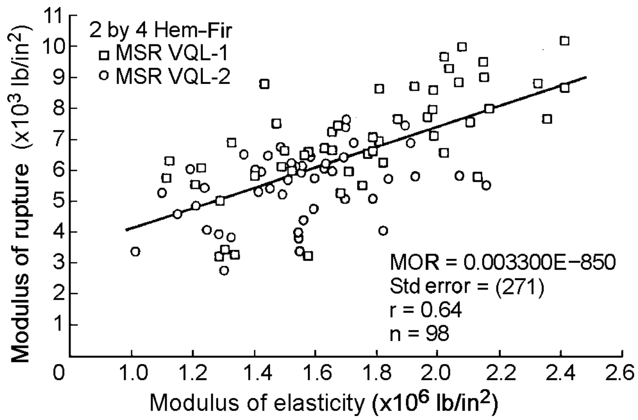


Figure 13—Relationship between modulus of rupture (MOR) and flatwise modulus of elasticity (E), as measured by static tester.

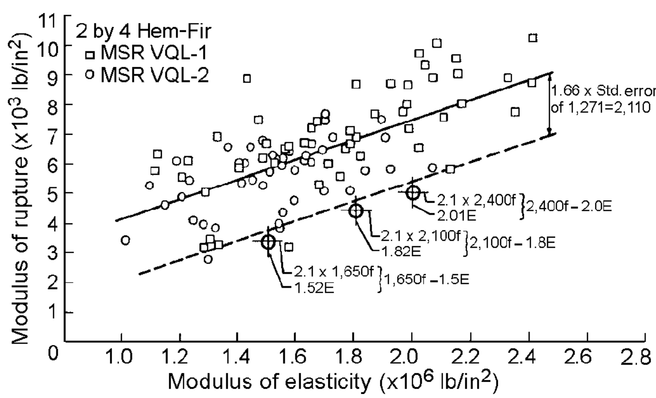


Figure 14—Estimate of average E required to maintain F_b of grade. Lower line is estimate of 5% exclusion limit for MOR for purpose of grade yield estimation process.

Another way to obtain this estimate when using the entire WWPA procedure (WWPA 1976) is to select, as the minimum average E for a grade, the value associated with an “A” of 3%, as provided in the WWPA certification procedure. Experience has shown that this number and the one selected from the graphical method just illustrated are nearly the same.

Once the average E required for each grade of interest is estimated, the fraction from each visual grade that the grading machine will be able to identify for each machine stress grade can be estimated. This estimate is also made in a rather arbitrary and graphic manner from E distribution histograms (Figs. 10 to 12, combined values). The assumptions for this estimation are as follows:

1. The E distribution histogram represents the stiffness content of lumber that will be presented to the grading machine for sorting on a continuing basis.
2. The minimum average E requirements of all grades will have to be met simultaneously from the E distribution shown in the histogram.
3. The estimating process is more concerned with the question "What is available?" than with grading machine behavior. (This assumes that machines can be adjusted or programmed to do the work demanded of them.) The main focus in this estimate is to answer the question "What is available?" and defers the question "How do we get it?"

The suggested procedure for making the estimate from the histograms is to start with the highest grade and work downward to the lowest grade. This assumes that it is desirable to obtain the best possible yield of high grades, allowing any compromise in yield to fall to the lower grades. Although this approach may not always be the most desirable one with respect to economic return and total machine grade yield, it will demonstrate how to make the estimates. The results of applying this idea to the Select Structural 2 by 4 lumber (Fig. 10) are shown in Figure 15.

First step—What fraction of Select Structural lumber will average the 2.01E that has been selected to satisfy the machine-stress-grade strength requirements?

The reasoning followed in answering this question is as follows. All the lumber classified as 2.0E and higher classes will satisfy this demand. How much of the lumber from the lower E classes can be included? In the histogram (Fig. 10), note that approximately 8% of the total expected lumber supply represented by the 103 pieces falls in the 2.1E, 2.2E, and 2.3E classes. Therefore, a conservative estimate is that 6% lumber from the 1.9E class can also be included, resulting in a 2.01E average. Thus, an outline is drawn, taking all 2.0E and higher E classes and 6% (6 pieces) from the 1.9E class. Adding all percentages of the histogram included in this 2.0E grade outline results in the inclusion of approximately 20% Select Structural 2 by 4's in the 2400f–2.0E grade.

Second step—From the lumber remaining after the 2.0E grade material has been removed, what fraction is available to provide an average E of 1.82 for the 2100f–1.8E grade?

Reasoning that all the actual 1.8E class pieces (14) and the 12% (12 pieces in this example) remaining in the 1.9E class are available, the percentage of the 1.7E class needed to provide the target average of 1.82E is found as follows:

$(12 \times 1.9) + (14 \times 1.8) + (x \text{ (pieces)} \times 1.7) = (12 + 14 + x) \times 1.82$

$48.0 + 1.7x = 47.32 + 1.82x$

$0.12x = 0.68$

$x = 6$ pieces 1.7E class

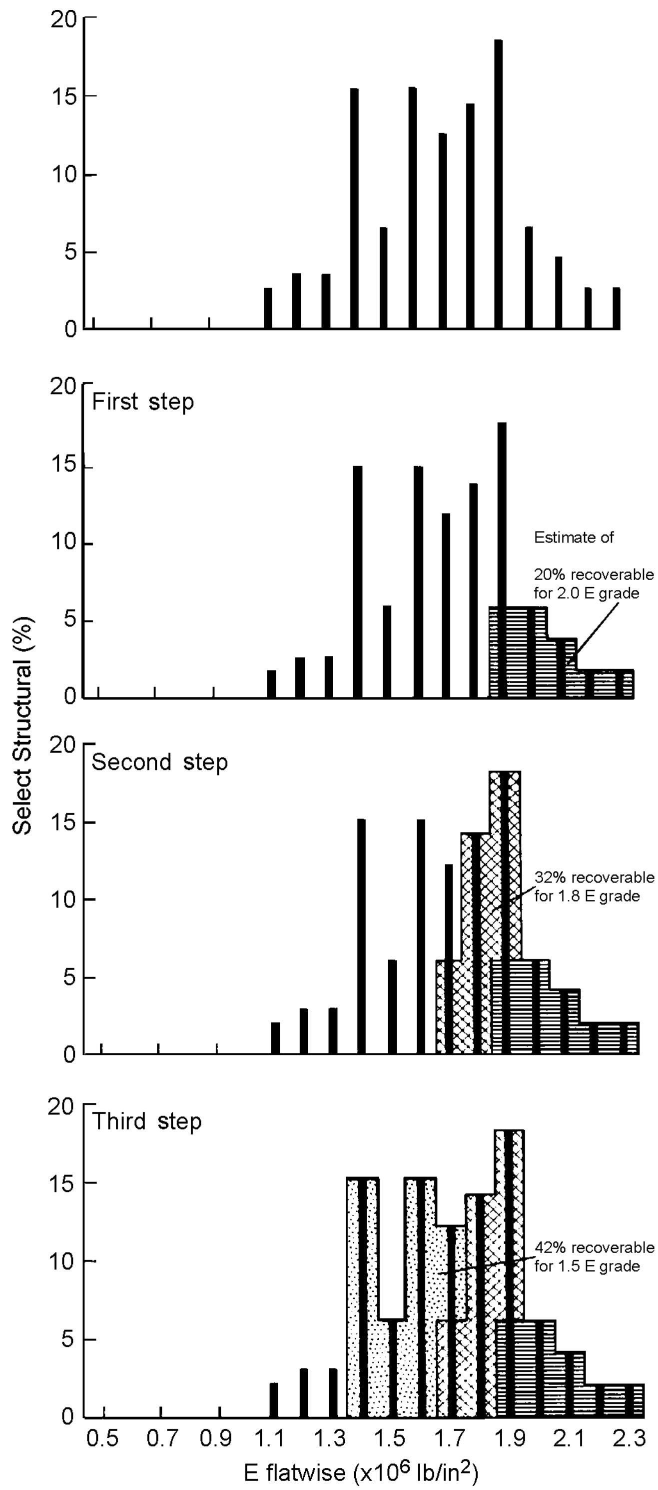


Figure 15—Procedure for estimating fraction of Select Structural 2 by 4's recoverable by E measurement. Data from Figure 10, combined results.

Thus, the estimate is that 32% of Select Structural 2 by 4's are qualified by the machine grading process for inclusion in the 2100f–1.8E grade.

Third step—How much material can be expected to be qualified from various E levels to produce an average E of 1.52 for inclusion in the 1650f–1.5E grade?

The 1.5E class, along with the material in the 1.4E and 1.6E classes, contains 36% Select Structural 2 by 4's and averages 1.50E. If the 6% remaining in the 1.7E class (6 pieces) is added, the result is an average E of 1.53 for the lot. Thus, an estimated 42% of Select Structural 2 by 4's are qualified by the machine grading process for inclusion in the 1650f–1.5E grade.

This procedure for estimating should also be applied to the E distribution histograms developed for Construction and Standard grades, as in Figures 16 and 17, respectively. If this rather arbitrary treatment of data increases concern about the reliability of the final results, remember that the objective is only to estimate the average yield expected. An alternative way of treating these histograms would be to redraw them, assuming a normal distribution with mean values and standard deviation of each as determined from the test data. The results estimated from these revised histograms would be similar to those developed from the raw data. As a last step in the estimating process, a range of estimated yields, both higher and lower than the average estimate, can be selected to test the sensitivity of the analysis.

The procedure outlined in the previous text answers three questions:

1. How much lumber is currently being produced that can be machine graded?
2. What fraction (or percentage) of this lumber is qualified for machine grading by the visual restrictions of the machine-stress-grading rules?
3. What fraction (or percentage) of this lumber is qualified for machine stress grades by the stiffness characteristics that are measured by the grading machine?

However, stiffness and VQL recovery are not relevant independently. Both estimates must be combined to obtain a single estimating factor for each machine grade recoverable from the 2 by 4 lumber resource.

The first step is to determine the fraction of each machine grade recoverable from each visual grade currently being produced. This is accomplished by multiplying the fraction qualified by the grading machine (E) by the fraction qualified by visual characteristics (VQL). The results of these computations are shown in Table 10.

Although the method of estimating the fraction of machine grades from VQL–l is reasonably straightforward, the method of determining the fraction recoverable from VQL–2 is not quite as obvious. In our example, the only machine

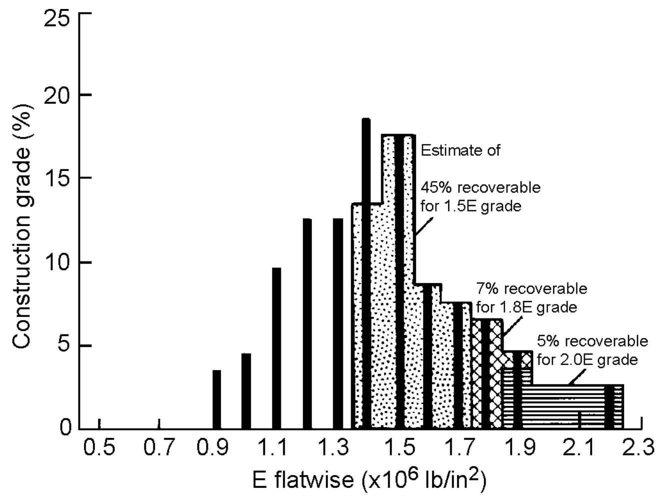


Figure 16—Estimate of fraction of Construction grade 2 by 4's recoverable by E measurement. From Fig. 11, combined data, using procedures shown in Fig. 15.

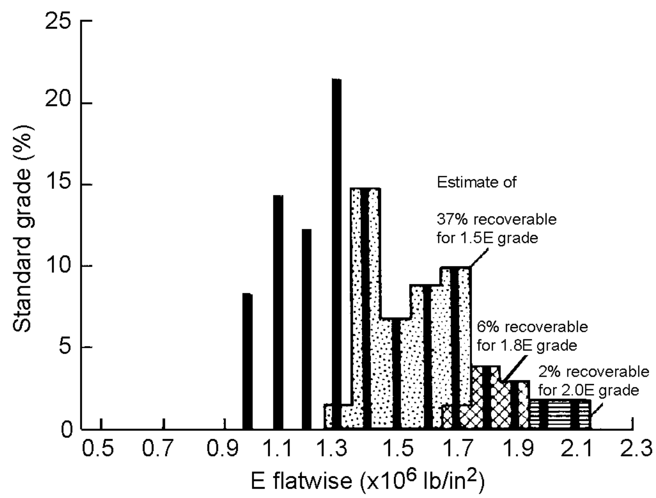


Figure 17—Estimate of fraction of Standard grade 2 by 4's recoverable by E measurement. From Fig. 12, combined data, using procedures shown in Fig. 15.

stress grade that can be made of VQL–2 is 1650f–1.5E. Therefore, on the basis of E measurement, it is assumed that a fraction equal to the sum of the fractions applicable to all three machine grades is recoverable. The total fraction of 1650f–1.5E recoverable is this number multiplied by the fraction of VQL–2 contained in the visual grade in question (Table 10). Actually, the VQL and E yields are not independent; experience has shown that the abovementioned assumptions are suitable for a feasibility analysis.

Table 11 shows the calculation of volumes of machine stress grades recoverable from all the 2 by 4's produced by the mill as a function of visual grade output (from Fig. 9) and machine grade yield (from Table 10). The rounded percentages from the resultant fractions are 2400f–2.0E, 2%; 2100f–1.8E, 3%; and 1650–1.5E, 19%.

Table 10—Estimate of recoverable fraction of machine grades from visual grades

Visual grade	Machine grade	Fraction qualified for machine grade: Machine E	Grader VQL–1	Grader VQL–2[a]	Fraction of machine grade recoverable from visual grade
Select Structural	2400f–2.0E	0.20	0.97		0.19
	2100f–1.8E	0.32	0.97		0.31
	1650f–1.5E	0.42	0.97		0.44
		0.94[a]		0.03	
Construction	2400f–2.0E	0.05	0.22		0.01
	2100f–1.8E	0.07	0.22		0.02
	1650f–1.5E	0.45	0.22		0.26
		0.57[a]		0.28	
Standard	2400f–2.0E	0.02	0.11		—
	2100f–1.8E	0.06	0.11		0.01
	1650f–1.5E	0.37	0.11		0.10
		0.45[a]		0.13	

[a]Fraction recoverable by E applied to VQL–2 is sum of fractions applicable to all three machine grades when applied to VQL–1. This assumes that actual distribution of E does not change with different machine grade VQL within visual grade of interest. This is not precisely true; the result is pessimistic with respect to yield of higher grades and optimistic with respect to yield of lower grades.

Table 11—Estimated machine stress grades recoverable from all 2 by 4's produced by mill as function of visual grade output

Visual grade	Lumber volume[a]: Percentage	Lumber volume[a]: Board feet	MSR grade	Fraction of machine grade recoverable from visual grade	Estimated volume of machine grade recoverable[a]: 2400/2.0	2100/1.8	1650/1.5
Select Structural	6	60,000	2400/2.0	0.19	11,500		
			2100/1.8	0.31		18,600	
			1650/1.5	0.44			26,400
Construction	55	550,000	2400/2.0	0.01	5,500		
			2100/1.8	0.02		11,000	
			1650/1.5	0.26			143,000
Standard	22	220,000	2400/2.0	—			
			2100/1.8	0.01		2,200	
			1650/1.5	0.10			22,000
			Total		16,900	31,800	191,400
			Fraction of total		0.017	0.032	0.191

[a]Board feet recoverable from 1 million board feet of 2 by 4's produced.

Table 12—Estimated proportions of 2 by 4 product mix under current and proposed visual plus machine product mixes[a]

Grade	Current product mix		Proposed product mix	
	Fraction	Board feet/ 10^6 board feet	Fraction	Board feet/ 10^6 board feet
MSR 2400f–2.0E			0.02	20,000
MSR 2100f–1.8E			0.03	30,000
MSR 1650f–1.5E			0.19	190,000
Select Structural	0.06	60,000	0[b]	
Construction	0.55	550,000	0.39	390,000
Standard	0.22	220,000	0.20	200,000
Utility	0.13	130,000	0.13	130,000
Economy	0.04	40,000	0.04	40,000

[a]Quantities based on assumed production of 1 million board feet of 2 by 4 lumber.

[b]Because <0.5% Select Structural lumber remains after machine grading, it is assumed to be included with Construction grade in Standard & Better grade mix.

The assumption has been made that the mill will market both machine grades and traditional visual grades where the quantities warrant the practice. However, this may not be the final decision of the mill because this type of analysis always exposes other alternatives for consideration. For the purpose of this example, the proposed mix of visual and machine grades is contrasted with the current product mix in Table 12. Of course, the fractions of Select Structural, Construction, and Standard in the proposed product mix are adjusted downward from the fraction in the current product mix in accordance with the portion converted to the machine grades. Table 12 completes the analysis. At this time, the data can be turned over to marketing and production managers for economic evaluation.

This method of assessing the capability of a mill for machine grade production has general application to different product mixes. This versatility becomes an important feature because production capability and economic evaluation are unique to each mill. Nevertheless, it must be reemphasized that this is not a precise analytical method. It is an estimation technique developed over a series of actual mill evaluations. It is sufficiently accurate to aid management in predicting the potential product mix by the introduction of machine grading, primarily in the 2 by 4 and 2 by 6 medium to high strength categories.

As noted, the principles of this analysis can be applied to E-rated grades, to grades generated with machines that measure density profiles rather than E, and to mixes of these and other grades, including grades intended for export as well as domestic use. The basic principles are to assure sufficient sample sizes of all component grades of interest, to make accurate measurements of both visual and mechanical features that affect yield, and to incorporate realistic values for mill production estimates.

If previous studies or production experience has identified appropriate grade sorting criteria (machine "settings"), modern data acquisition systems can access the computational systems of some machines to provide a rapid and potentially complete picture of yield using the device itself. Some modern machines now have this capability as part of their electronics package. This may have the very attractive alternative of using a large sample with a moderate to high speed system. Note that the output can be somewhat different than that achieved with a "laboratory-type" sorting device because production measuring errors (contributions) will be incorporated in the data.

Follow-Up Studies

When production has begun and marketing experience has been gained, there will be interest in increasing yield. Inquiries about different grade combinations will be made. At this point, it is useful to conduct a performance test of the grade matrix currently used to develop a better understanding of current grade performance and potential. This test also displays the predictive power of the grading system—reflecting the current mill wood qualities and quantities and the choices in effect for machine and visual grades, including any mill-specific grading "overrides." This analysis also provides a link to the predictive work completed before initiating machine grade production. Appendix C includes an example of one type of grade matrix analysis.

Mill Application

In consideration of the information presented in the previous sections, can some income be potentially gained? If so, what will the equipment cost? Will the net gain be attractive?

A variety of machines are available for mechanical grading of lumber. Some are production "in line" machines that can be used directly with a planer so that all input to the planer passes through the grading machine. By contrast, other machines are "off line" machines or machines that can be operated at 3 to 10 boards/min.

"In line" production machines operating in the United States are the Continuous Lumber Tester, the Stress-O-Matic, the Strength Grader, the Cook–Bolinder, the Dynagrade, and the X-Ray Lumber Gauge. (See Appendix D for information on manufacturers.) The first four machines are electromechanical in design; they establish the grade sort by response to piece stiffness by continuously, mechanically flexing the board over a set of rolls as the board passes flatwise through the machine. The Dynagrade uses stress wave transmission to measure the dynamic E of each piece by impact and sensing at the end. The X-Ray Lumber Gauge uses density profiles, rather than stiffness, as the measurement parameter, scanning the piece as it passes through the machine.

Although these machines are designed as in-line devices, all could be used off-line as well. Machine manufacturers are listed in Appendix D.

The E-Computer is the only production machine currently in use that is designed for off-line or operations in which the lumber throughput is slower. This is a transverse vibration system. A wider range of material sizes can be graded on these machines than on the higher speed, in-line machines. Rough material or material with a moderate amount of bow or warp can be stress graded with good results. Throughput for these machines can be measured in pieces/min and board footage, rather than linear feet/min, because sizes can be larger than 2 in. in thickness and materials handling can be the limitation.

Regulatory Acceptance

The most common use of grading machines is in production of lumber accepted by code and regulatory agencies for structural use. If strength properties are assigned (stress grading), the machine must meet the requirements of the Board of Review of the American Lumber Standard (ALS 1970) and the supervisory agency must be qualified for machine grade supervision by the Board. It is recommended that prospective purchasers of grading machines for machine grading contact an ALS-certified grading agency for current information.

If the grades to be produced are E-rated for the glued-laminated beam industry, the provisions of ANSI/AITC A190.1 and reference documents must be met (ANSI 1992, AITC 1993). Agencies supervising E-rating must be qualified under ANSI or ALS. Machines used for stress grading lumber are also candidates for grading E-rated laminating lumber. Criteria for grading, for quality control, and for approval are different than those for machine stress grading. Consequently, it is recommended that an interested producer contact a supervisory inspection agency for glulam timber or an ALS-certified agency that provides grade supervision in accordance with the ANSI-approved grades. These agencies are the authority for approval and subsequent quality control of a machine for E-rating.

Installation and Maintenance of Machines

High-speed machines can be arranged so that all material going through the planer passes through the machine. In the early days of grading, many machines were installed out-of-line so that only a selected amount of the material going through the planer passed through the machine. This was particularly important if the mill had a high-speed planer. As both electronics and materials handling technology advanced, speeds of up to 2,500 ft/min became possible. Currently available machines may have different speed capabilities, and reference to the specifications is required.

The variety of machines available today offers choice in mode of operation and environmental requirements. Some devices are heavier than others; some may require more isolation from the vibrations of a mill environment. An early limitation on all in-line machines was isolation from the planer; some models can now be close-coupled with the planer. It is also possible to mount a heavy machine on rails to permit lateral movement in and out of the path of production. This is particularly useful when some planer output does not need to be machine graded or the planer is being used for patterning, for example.

Costs

The price of machines and their installation cost generally vary in proportion to the production capability of the machine. Installation of a grading machine generally involves a reevaluation of existing planer mill and/or related facilities. Consequently, costs other than that for capital machinery must not be overlooked. The electronic circuitry and mechanical operation of modern machines are complex. Maintenance of modern machinery requires a technician with knowledge of both electronics and mechanics. Similarly, operation of the mandated quality control program requires personnel dedicated to the machine grading operation.

Of course, costs depend on specific mill programs and accounting. For example, material handling, sorting, quality control, and a well controlled drying program contribute to production costs. The proportion of these costs charged to mechanical grading varies by mill.

Auxiliary Lumber Handling

It is assumed that the costs of installing an in-line production machine will be comparable for a planer mill installation, regardless of the machine model. All in-line production machines require such items as vibration-free foundation, electrical source, and maintenance provisions. The related transfers and conveyors can be of the same general design for any machine. The number of these peripheral systems and their specific design depend on the material flow pattern chosen. Once the search for a machine has been narrowed to specific candidates, a more careful analysis of installation needs can conducted. An example is the capability of some modern machines to be close-coupled to the planer, thus easing the requirement for some transfer equipment.

All production machines, if installed out of line with the planer, must have an in-feed table that will deliver individual pieces to the machine at a speed compatible with the machine's operating speed. This involves a singulator for feeding one piece at a time onto an accelerator table so that the pieces move at the same speed as the machine.

The arrangement of the machine grading equipment in the mill usually depends on the existing mill flow and the production requirements. The figures in Appendix E illustrate arrangements of machines and essential auxiliary equipment that will permit estimating specific capital investment and installation costs. If only part of the material that goes through the planer is to be run through the grading machine, a flow plan similar to those shown in Figures 18 to 24 in Appendix E is used. In some instances, it is practical to provide an in-feed to the stress tester without going through the planer. Such an arrangement is shown in Figures 20 and 21, Appendix E.

If all the material that is run through the planer can also go through the grading machine, the grading machine can be directly in line with the planer (App. E., Fig. 25). This type of an installation may be the least expensive because of the limited number of transfers and conveyors, but a machine bypass and re-trim capability may be desired to provide flexibility. If the bypass with the lift-up conveyor (Fig. 25A) is not needed, modern machines are often mounted very close to the planer (Fig. 25B).

In all cases, it is necessary to visually check–grade the lumber after it passes through the stress rating machine. Provisions for this step vary with mechanical arrangements as shown in Appendix E.

Quality Control

The successful and profitable utilization of machine grading in a mill depends in a large part on how committed the mill is to a quality control program. This program should start with the log breakdown into lumber and follow through all phases of the operation.

1. The sawing process should consistently produce lumber that is dimensionally accurate. In-line machines based on stiffness measurement are sensitive to off-size because they depend upon contact between sensing elements and rolls and the flat surface of the piece. All in-line machines assume a constant size for the calculation of mechanical properties.

2. Log bucking and lumber grading and sorting in the sawmill should be carefully planned to emphasize development of the particular grades of interest (generally the higher grades) for machine grading.

3. The dry kiln operation must produce lumber of a consistent and controlled moisture content. Proper sticker placement not only affects efficient drying but minimizes warp that can influence the grading machine. Insufficiently dried lumber will likely be misgraded by the machine because of the influence of moisture on the measured variable (for example, stiffness or density). Some machines are qualified for use with dry lumber only. Some machines are used for either green or dry; however, special qualification steps are taken with green lumber.

4. The output of the mechanical grading machine must be monitored for accuracy. Mechanical and electrical settings can get out of adjustment or be affected by mechanical damage. These concerns are addressed through the quality control program of the grading agency as well as normal mill maintenance.

5. The visual plus machine concept of machine grading processes requires careful review of not only the mechanical stress grading machine but also the grading for visual characteristics. Guarding against too conservative a visual grading process is an element of a good program.

Maintenance

Routine maintenance of grading equipment is important. Although recent technologies reduce problems with some grading machines, this equipment is generally sensitive to such things as temperature, humidity, vibration, noise, dust, and debris.

Any mechanism that operates at more than 400 ft/min in a mill environment requires regular maintenance of parts such as bearings and belts. Guards, shields, and other protective devices should be hinged or otherwise built to encourage routine maintenance and inspection of machine components.

Most grading machines, particularly those mounted in-line, are complex electromechanical devices. A malfunctioning in-line arrangement loses production time. Anyone considering the installation of a machine grading system should also consider hiring a qualified technician to service and maintain it. This person can also run the static test sampling and keep grading agency records.

Certain optional and calibration troubleshooting equipment, such as oscilloscopes, may also be desirable. Obviously, the test equipment must also be kept in good calibration and repair.

Because most deflection machines use the principle of a load cell or transducer to indicate stiffness, any interfering vibrations will appear as transducer output signals. This can be overcome by (1) surfacing lumber to close tolerances for finish, (2) isolating vibrations, and (3) using special electronic filter circuits. All practical efforts should be made to support the equipment on dynamic shock pads and minimize internal machinery vibrations. These practices will lead to more accurate measurements and longer equipment life.

One other precaution is to regulate temperature, humidity, and dust in the vicinity of the electronic equipment. This is usually done by housing as much equipment as possible in a temperature-controlled room and filtering out dust and contaminated air. Temperature control has been shown to be particularly valuable where seasonal extremes are severe and where daily temperature variation commonly exceeds 25°F to 30°F during the operating period.

Keeping spare parts on hand will significantly minimize lost production time. Fortunately, much electronic circuitry of machine grading devices is built with plug-in printed circuitry. By keeping spare circuit boards on hand, it will not be necessary to completely isolate a problem but merely to determine which part of the circuit is affected and replace that particular board. Repairs can then be made at the convenience of the technician.

For machine grading equipment, as for other equipment, routine maintenance and inspection "doesn't cost—it pays."

Associated Concerns

Mill Flow

As Figures 18 to 25 (App. E) indicate, many planing and grading arrangements are possible. In the early days of machine grading, a popular arrangement was to place the stress grader out of line, permitting grading of only preselected grades or species. An alternative arrangement was to establish a separate grading facility, such as a grading station independent of the planing mill (perhaps located at the shipping shed or in another convenient location). Selected loads could be brought to the facility, then graded and returned. This arrangement allowed the grading machine to be used on an occasional basis without disturbing the main mill flow. Specialty manufacturers might prefer a separate grading station as it allows them to purchase selected grades from other mills and merely upgrade the material for its intended use. Secondary manufacturers, such as glued-laminated beam plants, commonly use this approach for E-rating laminating lumber.

The recent innovation of placing the grading machine on a movable base so that it may be moved in or out of an in-line position with the planer allows mill flexibility. Some machines may be "opened up" and the grading function disabled so that material can pass through without being machine graded.

Drying

Lumber drying is clearly connected with all types of grading and is particularly important in machine grading. Stiffness, strength, and density are all affected by moisture content. Wood increases in stiffness and strength as it dries; however, in lumber form, wood strength may decrease when the lumber is dried to too low a value. The general grading agency moisture content targets of 15% maximum (12% average assumed) or 19% maximum (15% average assumed) are appropriate if the "low" end of the moisture distribution is controlled to prevent excessive overdrying.

Loose knots, checks, honeycomb, warp, and collapse are other results of unequal shrinkage that can affect strength. Other seasoning degrade may primarily affect appearance rather than strength. Obviously, suitable drying schedules and uniform moisture content are requirements for any stress grading operation.

If the grading operation is based on E measurement, another aspect of drying that must not be ignored is lumber temperature. After the lumber leaves the dry kiln, sufficient time must be allowed for it to cool because the E value declines with increasing temperature; insufficient cooling time will result in reduced yield.

Commercial Machine Selection

Selection of a grading machine is mill-specific and should be closely tuned to the anticipated marketing scheme of the owner. The following issues should be addressed when selecting a machine.

Mill Criteria

- Anticipated sizes (width, length, thickness) of lumber to be graded
- Anticipated species and moisture levels
- Marketing goals—not only grades but also quantities of grades and grade combinations
- Planer operating speed for in-line operation; anticipated production rate and up-time for out-of-line operation
- Special concerns
    - Available space
    - Proximity to planer
    - Proximity to ancillary equipment
    - Mill environment (temperature, humidity, vibration, electronic noise)
    - Maintenance and quality assurance[3]

Machine Specification

Specification criteria vary by application and mill requirements. The differences in design features of modern machines allow the owner to select an appropriate device to meet mill needs. The following is a basic check-list of concerns that should be reviewed.

[3]Experience has shown that grading machine maintenance often requires staff who understand the mechanics and electronics of the machine and the properties of the lumber. Part of the mill quality assurance program will need to be devoted to this grading system. In particular, under the guidance of the supervisory agency, the mill will need to conduct lumber sampling and testing.

1. Flow (continuous or stop & go)—Some machines take multiple measurements as the piece passes through the machine; others take one reading as the piece momentarily pauses.

2. Lumber travel (lengthwise or transverse)

3. Lumber orientation—Some machines test with lumber in a flatwise position; others require pieces to be turned on edge.

4. In- and out-feed—Efficiency of some machines is improved by proper speed, support, and orientation of in-feed and out-feed devices that are not an integral part of the grading machine itself.

5. Physical environment—Grading machines are complicated, involving moving machinery and electronics to measure very small differences in physical and mechanical properties of the lumber. The environment may have a greater effect on these devices compared to other equipment in the mill. Sensitivity to mechanical vibration, temperature and humidity variation, and electronic noise can be critical.

Product Acceptance

So that a mill can be qualified to machine grade under ALS PS–20, the grading machine must be certified under ALS (ALS 1970). Some machines are used to produce E-rated grades under ANSI/AITC A190.1 (ANSI 1992). These machines are not formally certified under ANSI; however, the supervision of the grading, both visual and machine, is conducted under the standard.

Machines used to develop machine grades in North America in 2000 under ALS PS–20 or ANSI/AITC A190.1 are listed in Appendix D.

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Appendix A—Nomenclature, Performance Criteria, and Allowable Properties for Machine Grades

Nomenclature

When machine grades first reached the market, the terminology used to describe the grades identified the process (the function of the device). The process used by the Continuous Lumber Tester (CLT) was called ElectroMechanical Stress Rating by the originators, the Potlatch Corporation. This name was abbreviated as EMSR and was stamped on the lumber, along with the stiffness code, during the first 6 to 8 years of production by some CLT users. The significance of this label was to emphasize that the machine process integrated both electrical (load cells and electronic analysis) and mechanical (bending lumber to prescribed radius) means to achieve a measurement on which the lumber sort was based. The other common machine grading device was the Stress-O-Matic. The early version of this machine was principally a mechanical device, depending on hydraulic loading. The terminology assigned to this process was Machine Stress Rating or MSR. In time, the term EMSR used in conjunction with the CLT was dropped, other machines were accepted by ALS, and the use of any mechanical device was labeled MSR.

For several years, no visual restrictions that related to allowable stress assignment were placed on MSR lumber. Even after restrictions on the size of visual characteristics were added, the term MSR continued to signify that a grading system had been employed that used a mechanical device. In essence, from 1962 until about 1996, the term MSR was a generic acronym meaning the use of a mechanical system for stress grading, regardless of the type of machine or different visual overrides, supervisory agencies, or agency requirements. Stress-graded lumber using a machine system was required to include the term MSR or Machine Rated on the grade stamp.

In 1996, the American Lumber Standards Committee (ALS) adopted a different procedure for nomenclature associated with grading processes that depend on machines. This new procedure assigned a “name” or acronym according to how the lumber was qualified by test, not by the process of grading. Consequently, the term MSR no longer covers all grading processes in which a machine is employed; it has been redefined to apply only to mechanically graded lumber that meets certain qualification (performance) criteria. This change corresponded with creation of a new category, Machine Evaluated Lumber (MEL). The existence of both terms, MSR and MEL, plus the “E-rated” laminating machine grades, requires distinctive labeling linked to the different performance criteria.

Performance and Grademark Criteria

ALS performance criteria for MSR, MEL, and E-rated lumber are shown in Table 13. MSR and MEL performance criteria differ in the variability permitted in MOE (criterion 2) and the additional performance criterion for MEL (criterion 4), which adds the requirement for strength qualification of MEL grades in tension. E-rated lumber is not stress graded but sorted for MOE, with associated visual requirements. This lumber is recognized under both American Lumber Standard PS20–99 and ANSI/AITC A190.1 for lamina of glued-laminated beams (ALS 1970, ANSI 1992).

The grademarks used with machine grading are distinguished from visual grade labeling requirements by the presence of allowable design values on the grade stamp. Table 13 includes a generic list of grademarks and practices for MSR, MEL and E-rated lumber; practices of specific labeling may vary by agency. Other regular requirements, such as moisture content, also apply.

In addition to ALS label content requirements and documents referencing ANSI/AITC A190.1, the supervisory grading agencies have jurisdiction over specific grademark criteria and design. Consequently, some differences in symbols or presentation may be expected. The following are commonly accepted definitions. Restrictions on size and clarity may influence the specific symbol selected for a grademark.

MOR — modulus of rupture (lb/in^2)

MOE — modulus of elasticity, often shown as E ($\times10^6$ lb/in^2)

Note: MOE is a generic term, but it usually signifies the mean of the distribution of MOE values or the allowable design MOE, often the mean of the grade.

MOE_{mean} — mean of a distribution of MOE values, as in E-rated criteria

MOE_{5th} — 5th percentile MOE value in a distribution of MOE values

UTS — ultimate tensile strength (lb/in^2)

f, f_b, F_b — allowable design value in bending on edge (lb/in^2); symbolism may vary slightly

f_t, F_t — allowable design value in tension (lb/in^2); symbolism may vary slightly

E — abbreviation for MOE ($\times10^6$ lb/in^2)

The description and labeling of grades and the associated design values are found in the literature of the grading agencies. These are the basic references for grades and labeling since the grading rules and associated documents are kept up

Table 13—ALS performance and grademark criteria for MSR, MEL, and E-rated lumber[a]

Machine grading process	Performance criteria	Grademark criteria
Machine-stress-rated (MSR)	1. The average edge MOE shall be equal to or greater than the average edge MOE assigned for design.	Shall contain the term "MSR" or "Machine Rated," the design F_b, and MOE (stated as "E"). Example: 1950f 1.7E Machine Rated.
	2. 95% of the pieces shall have the edge MOE greater than 82% of the edge MOE assigned for design.	
	3. 95% of the pieces shall have the MOR greater than 2.1 times the F_b assigned for design.	
Machine evaluated (MEL)	1. The average edge MOE shall be equal to or greater than the average edge MOE assigned for design.	Shall contain the letter "M" associated with a term, such as "16", related to an explicit set of allowable design values; in addition, allowable MOE, F_b, and F_t shall be on the grademark. Example: M-16 1800 fb 1300 ft 1.5E.
	2. 95% of the pieces shall have the edge MOE greater than 75% of the edge MOE assigned for design.	
	3. 95% of the pieces shall have the MOR greater than 2.1 times the F_b assigned for design.	
	4. 95% of the pieces shall have the UTS greater than 2.1 times the F_t assigned for design.	
E-rated[a]	The relationship between the mean MOE and the lower 5th percentile MOE is a sliding scale, with a tighter requirement on the higher MOE grades. The relationship is expressed as $MOE_{5th} = 0.955MOE_{mean} - 0.233$, where mean MOE is the value assigned to the grade for the design of the layup of glued-laminated beams.	Shall contain MOE that characterizes lamina for the glued-laminated beam layup design; shall also contain notation signifying the maximum edge characteristic permitted in grade. Example: 1.8E-6, where 6 indicates the maximum edge characteristic permitted in grade as a fraction (1/6) of the cross section.

[a]Criteria for E-rated lumber originate in ANSI/AITC A190.1.

to date. A complete listing of all machine stress grades is found in the *NDS Supplement—Design Values for Wood Construction*, table 4C, Design values for mechanically graded dimension lumber. This listing may not always be up-to-date because of the publishing schedule. In addition, it is limited to mechanically graded stress grades and consequently does not include E-rated grades.

Allowable Properties

A standard series of allowable property combinations was employed during the first 20 or so years of machine grading. These property combinations used a regular increase of allowable bending, F_b, with equal increment increases in modulus of elasticity E; for example, 1500f–1.4E, 1800f–1.6E, 2100f–1.8E. All species, lumber widths, and geographic areas were expected to fit into this array. Early testing of commercial grades emphasized narrow widths, limited sample sizes, and evolving standards for operation and quality control. In this environment, the standard series of F_b–E combinations served well, in both yield and marketplace performance.

More testing was emphasized over time, and qualification standards became more sophisticated. Mills explored the performance of additional widths, and by the 1980s, testing of full-sized lumber in tension as well as bending became feasible. The influence of width was identified to be about the same in machine grades as in visual (Galligan and others 1993), geographic influences were recognized by those purchasing from different areas, and assignment of tension allowable properties through the traditional ratios of tension to bending was challenged (Galligan and DeVisser 1998). Equally important, producers began to focus on "user efficient" sets of properties for the truss and glued-laminated beam markets. The result of these influences was the development of new machine grade property combinations—combinations that deviated from the standard series steps of F_b–E.

An early example demonstrates both the flexibility of machine grading and the market focus that this permits. In the 1970s, the 1500f–1.4E grade—the "bread and butter" grade of the 1960s for the metal-plate truss industry—was switched to 1650f–1.5E. This was in response to changes in the corresponding visual grade assignments and thus was necessary to maintain markets challenged by the visual grades.

Soon after the advent of the 1650f grades, testing of wide widths demonstrated the influence of size. In essence, qualification of a wide width for the same F_b as a narrow width required maintenance of a higher E level. In other words, although the traditional F_b–E steps provided good guidance for narrow widths, they were inadequate for wide widths, especially if both tension and bending were examined by test. The following table is a schematic example of the influence of width on commercial machine grades. The E values in the table are the design levels (mean of the grade) that would have to be maintained to qualify all the widths shown to the same F_b levels.

Grade F_b	Grade E to meet F_b and F_t requirements for different lumber sizes		
	2 by 4	2 by 6	2 by 8
1800	1.7	1.8	1.9
2100	1.9	2.0	2.1
2400	2.2	2.3	2.4

This table, while based on actual test observations, is illustrative only because mill qualification under agency supervision is essential in making actual grade property decisions. Nevertheless, a mill will recognize the yield implications from the illustration. The yield concern can become further aggravated by the fact that the wider material often must be cut from a portion of the log that does not match the E capability of the outer portion from which the narrow lumber can be cut.

Note that the table also challenges some traditional series combinations. Even for 2 by 4 lumber, the 2400f–2.0E grade is suggested to become an actual 2400f–2.2E grade, based on qualification. This may result from a more thorough qualification that examines both F_b and F_t. If this occurs, a 2.2 mean grade E may be required to maintain the 2400 F_b and its traditional 1925 F_t value. Thus, this testing has raised the issue of the traditional assignment of F_t based on F_b.

F_t/F_b Ratios

The application of the traditional F_t/F_b ratios, which are listed in FPL–GTR–28 (Galligan and others 1979), has been examined by research at the West Coast Lumber Inspection Bureau (Galligan and others 1979, Galligan and DeVisser 1998). In summary, the 0.8 ratio of F_t/F_b used traditionally for assignment of properties to machine grades of 2400 F_b and higher is not always verified in qualification tests. Consequently, if the qualification test results in a ratio of 0.7, for example, the mill may choose to continue to market a 2400 F_b grade but assign a 1680 F_t value instead of the traditional 1925 F_t. A second option, assuming test verification, is to hold the traditional 1925 F_t value because of the interest of the truss market, for example, but then to raise the claimed F_b to 2,750 lb/in^2. Clearly, the simplicity of a standard set of ratios and grade levels is disrupted by these test-based discoveries. On the other hand, the opportunities are in tailoring the grade to both the resource and the customer.

Marketing

The complexity of all possible combinations of properties introduces the realities of marketing. In the example described in the section on F_t/F_b ratios, the market choice may be neither of the choices shown; that is, neither a 2400 F_b/1680 F_t grade nor a 2750 F_b/1925 F_t grade. The choice for marketing communication and simplicity could be to continue to market a 2400 F_b/1925 F_t grade. However, if the test data require acknowledgment of a real F_t/F_b ratio of 0.7, the *grade-limiting* property will be 1925 F_t and F_b will actually be at the 2,750-lb/in^2 level (and maintained there), even though marketing requires stamps of 2400 F_b. The ultimate choice of grade assignment in this situation is a combination of concerns for mill yield, marketing simplicity, and customer requirements.

It is also important to look at the influence of piece size on marketing choices. If the relationships shown in the previous table are assumed as well as a mill interest in marketing 2 by 4 through 2 by 8 lumber in each grade shown, can the market accept a series of grades that may have the same F_b and F_t value but different E values? An example would be the 2100f grade shown with E values that vary from 1.9 to 2.1 by width. The marketing manager may recommend marking 1.9 on all three sizes, giving up the actual higher E values being maintained by quality control to simplify to marketing.

Another important example is in E-rated grades for the laminating industry. Grades for laminating are usually qualified with characteristic data developed from 2 by 6 lumber. As a consequence, the E level of that size may dictate the E value assigned to the grade, whether it is 2 by 4, 2 by 8, or another size. For example, mill selection may dictate a higher E level for 2 by 8 lumber, but it may not be claimed on the E-rated grade if this value cannot be used by the laminating layup system.

One purpose for emphasizing marketing input is to point out the essential difference between the reality of the test results in qualification and the need to communicate to the customer a useful series of properties. It is sometimes difficult in this new world of machine grades for the marketing segment to appreciate how the properties are driven by qualification and quality control. However, these test-based numbers only set the stage—the upper limit, in most cases—for what claims the mill may wish to make in the marketplace. At this point, the marketing realities must "kick in" and the trade-offs in yield must be balanced with customers needs; the test-based results only set the outside limits of the process.

This publication can only point out the variables that can be observed in the process of assigning properties to machine grades. Each mill may have resource, processing, testing, and marketing realities that are specific to that operation. Furthermore, the resulting grade assignments will be under the auspices of ALS or ANSI/AITC. All of these considerations are important in considering grade assignments.

Appendix B—Selection of Mill Samples for Strength Tests

1. Select approximately 200 pieces of each grade.
2. Calibrate the E measuring device. If the static tester (Fig. 8) is used, weights should be accurate to within 0.1 lb.

   [To be consistent with the yield exercise of the text, the material in Appendix B assumes a stiffness measurement system. For density-based systems, substitute density measurements in the discussion. Accuracy requirements for any grading system should be determined with the supervisory grading agency and the machine manufacturer.]
3. Grade stock for visual quality level (VQL) and visual grade.
4. Label (code) each piece, then determine moisture content and E or deflection and record these data and the two visual grades (see Fig. 7). Record deflection to nearest 0.001 in. Data collected should include the following information for each piece:
   a. Piece number (code)
   b. VQL
   c. Visual grade
   d. Lumber moisture content at time of plant deflection test
   e. E measurement or deflection on plant static tester; location where E or deflection was taken should be marked on "up" side of piece
5. Select specimens for strength tests to provide a sample stratified on E and VQL; this means approximately equal numbers of specimens at all possible levels of E and VQL should be selected, if possible. To do this, specimens previously divided into VQL classes are further divided into narrow E classes. Equivalent deflection classes can be used if the E values have not yet been computed. Specific specimen numbers for test can then be randomly selected from each category—the same number from each.

The following data sheet for VQL–1 is an example of one way to divide and record specimens for testing. Similar sheets are used for other VQLs. Note that it is difficult to fill E categories at both extremes of E, and this is also influenced by VQL. Practical rules for sampling must be adopted; grading agencies will have specific instructions.

Data Sheet for VQL–1 Sample

Plant E range ($\times 10^6$ lb/in^2)	Equivalent deflection range (in.)	Piece number				
		1	2	3	4	5
<0.55						
0.55–0.70						
0.70–0.85						
0.85–1.00						
1.00–1.15						
1.15–1.30						
1.30–1.45						
1.45–1.60						
1.60–1.75						
1.75–1.90						
1.90–2.05						
2.05–2.20						
2.20–2.35						
2.35–2.50						
2.50–2.65						
2.65–2.80						
>2.80						

Appendix C—Matrix Evaluation

Visualizing relative grade yield and the possible grade potential with respect to actual strength performance of the mill grades is often difficult in the mill environment, where primary emphasis is often placed on meeting (and not overstating) grade strength criteria. But how "rich" are the grades? What is the strength profile of each grade with respect to the adjacent grades in the grading matrix? Is there a potential for improved yield? For different grade combinations?

The evaluation of a set of mechanical grades can be visualized as a matrix diagram in which five grades are all proof loaded to the design level of the highest grade. The performance of each grade is measured against both expected performance at the near minimum strength level (5% point estimate) and the percentage of pieces that would qualify for a higher strength grade if they could be identified in the grading system. If the grading system were "perfect," exactly 5% of each grade would be below the target value for the grade and each grade would be tightly grouped by strength into a unique group (no overlap in strength between grades). Both of these concepts are basically unobtainable in the practical world of mill grading. The matrix test of mill grades gives the "real world" view of the grades produced. The grade matrix evaluation is presented in more detail in Galligan (1985).

To conduct a meaningful matrix evaluation, it is necessary to test all mechanical grades and, preferably, the highest "reject" or visual grade below the lowest mechanical grade. Any of the allowable properties can be used. However, it is important to choose the property to be tested with an eye toward market sensitivity, qualification results, or performance concerns. Matrix test results for more than one property may yield different results; for example, grades showing significant "underutilization" in bending strength may give different results if the matrix is based on tensile strength.

To place this test information within the current mill yield scenario, the grade samples must reflect the relative production yields. There are two ways to do this. The first is simply to sample the grades in proportion to their production, keeping in mind that the grade with the lowest yield will set the minimum sample size. The second method, frequently used for convenience, is to select an equal small sample of each grade and then weight the test results with production yield figures. Testing and sample costs may encourage small samples; however, the probable resultant inaccuracy should not be underestimated. Samples of 100 or more pieces per grade are suggested. With suitable sample sizes, the results can be compared with the grade yield projections made in the text (Assessment of Production Potential).

An example employing four mechanical grades and one "reject" will illustrate the process. The mechanical grades selected have assigned allowable properties in bending strength of 2400f, 2100f, 1650f, and 1450f.

1. Sample sizes arbitrarily selected for this example are 100 pieces each for 2400f and 2100f, 400 for 1650f, and 200 each for 1450f and "reject" to correspond to approximate yields of 9%, 9%, 36%, 27%, and 18%, respectively, of this example production.
2. Samples are then proof loaded to 2.1× the design of the highest (2400f) grade. Each grade below 2400f contains more broken specimens than does the next highest grade, allowing inferences of strength capability.
3. When the data matrix is complete, the number of pieces failing below the target for each grade can be seen by totaling the values in the matrix cells below the target. The values in the cell above the target strength level cell are pieces with strength capability of grades higher than assigned.
4. Summations give the relative strength capability of the production lot. Comparison with the percentage yields of the grades gives a realistic measure of the efficiency of the grading system, including the influence of decisions by the mill on grade choices and other factors such as visual overrides and log selection.

An example matrix is placed at the end of this appendix. To explore the results for one grade, select the column that corresponds to the grade. For example, select the 1650f column under grade assignment. Of the 400 pieces tested, 67 survived the 2400f proof level. Of those that failed the proof load, 101 were less than 2400f in strength but equal to or better than the 2100f proof level; 208 of the 1650f pieces failed with test values that equaled or exceeded the 1650f accept level but were less than the 2100f proof level. Twenty-four pieces (6%) failed below the 1650f accept level of 3,465 lb/in^2, suggesting a more thorough analysis may be in order or an adjustment is needed in the grading process to lower this value below 5%.

The matrix Summary shows the results from the shaded cells; 4%, 3%, 6%, and 5% of the test sample broke below the grade target levels for 2400f, 2100f, 1650f, and 1450f, respectively. The total strength "potential" of the lot is shown from the horizontal summations to be 18.6% for 2400f and above, 18.8% for the 2100f level, 27.4% for 1650f and 22.6% for 1450f, with 12.5% not meeting the 1450f level requirement—compared to the current mill production yield of 9%, 9%, 36%, 27%, and 18%. This fictitious example suggests that this strength capability is not being "found" by the current grading system. Also, the "reject" percentage may be too high. In reality, only the pieces set in bold italic are really being "understated" by the current grading process. These would be the pieces worthy of further grading analysis. The "understating" of many pieces is not surprising because the grading model is not perfect. Furthermore, the necessarily finite grade boundaries distort the "perfect" scenario. Nevertheless, matrix results always provide data for thoughtful review of grading efficiency (both manual and machine), grade selections, and mill process control.

Basic assumptions are important in running a matrix test. These often are based on the practical aspects of mill operation and marketing focus. The example matrix assumes that the highest current grade would be used to set the defining proof load level. A higher proof load level could be used to better evaluate the high end of the strength spectrum. For example, even though the mill currently manufactures nothing higher than 2400f, if the proof load level were set to correspond to an assigned value for a 2850f grade, more information on the strength spectrum would be developed.

Another assumption is that the grades are being evaluated just as developed by the grading technology that the mill has selected; that is, the matrix does not address the selection criteria for the grades. Only one grade characteristic property is considered in this one-dimensional analysis. For example, a grade may be limited in mechanical grading by stiffness criteria or by a limiting qualification in tension, yet bending strength may be chosen as the basis for the matrix to develop technical marketing data. If the grade is stiffness limited, the surplus bending strength may be out of reach unless the allowable property claims for the grade are revised. If the grade is known to be more restricted by tensile performance than by bending strength, a test based on tension may be advised. In the same manner, the matrix results will be affected by any special VQLs (visual overrides) that the mill has chosen for marketing reasons.

Example grade matrix for mill producing four machine grades[a]

		Grade assignment						
		2400f	2100f	1650f	1450f	Reject	Total	Performance
Test/criterion level								
Proof load level (2400f × 2.1)	5040	96	***33***	***67***	***9***	—	205	18.6% @ 2400f or better
2100f accept level	4410	3	64	***101***	***39***	—	207	18.8% ≥ 2100f but <2400f
1650f accept level	3465	1	2	208	***60***	***30***	301	27.4% ≥ 1650f but <2100f
1450f accept level	3045		1	24	186	***38***	249	22.6% ≥ 1450f but <1650f
Loads < 1450f level	—				6	132	138	12.5% <1450f
Summary								
Total pieces		100	100	400	300	200	1100	
% production		9.1	9.1	36.4	27.3	18.2	100.1	
Pieces < accept level		4	3	24	6			
% < accept level		4	3	6	5			

[a]Sample sizes were chosen to represent current mill yield. Proof load level and grade "accept" levels are expressed in pounds per square inch. All mechanical grades and "reject" grade were subjected to proof load in bending of 5,040 lb/in^2, corresponding to the allowable bending strength for 2400f. Data in box represent pieces that survived (row 1) or failed (rows 2–5) proof load, falling in the range indicated in the rightmost column. Shading indicates pieces that fell below accept level for the grade. Bold italic type indicates pieces that would qualify by bending strength for a higher grade. Data in cells on diagonal refer to pieces "correctly" sorted by grading process to target category of bending strength.

Appendix D—Commercial Grading Equipment

The following list includes U.S. commercial grading machines in 2000 that are operating under a recognized concensus standards organization. The versatility of these modern machines and the variety of both installations and machine graded products make it critical for prospective users to contact the manufacturers for details on operating characteristics, installation requirements, and associated costs. Coincident communication with the appropriate supervisory grading authority is strongly recommended.

Machine	Manufacturer
Cook–Bolinder [Model SG-TF NA]	Cook–Bolinder Ltd. P.O. Box 42 Stansmore, Middlesex HA7 4XD Great Britain
Stress-O-Matic	Crow Machines 109 S. Kirby, Suite 405 Garland, TX, 75042 USA Phone: (972) 272-7322 Web Site: www.crowmachines.com
Dynagrade	Dynalyse AB Brodalsvagen 7 SE 433 38 PARTILLE Sweden Phone: +46 314 486 32 Fax: +46 314 486 05 Web Site: www.dynagrade.com
Strength Grader [ESG-240]	John Ersson Engineering AB Vallbyvägen 101 S-812 90 Storvik Sweden Phone: +46 290 107 00 Fax: +46 290 102 42
Continuous Lumber Tester [CLT, HCLT] Transverse Vibration E-Computer	Metriguard, Inc. P.O. Box 399 Pullman, WA USA Phone: (509) 332-7526 E-mail: sales@metriguard.com
X-Ray Lumber Gauge [XLG]	Newnes Machine Ltd. P.O. Box 8 Salmon Arm, BC, V1E 4N2 Canada Phone: (250) 832-7116

Appendix E—Mill Arrangements for Grading Machines

The figures in Appendix E (Figs. 18–25) illustrate arrangements of machines and essential auxiliary equipment that will permit estimating specific capital investment and installation costs. These sketches are based on installations from 1963 through the 1970s. The arrangements shown encompass most modern operations; however, as noted, important additions include installations with the grading machine on rails to permit lateral movement in and out of line with the planer and provisions in some machines for close-coupling to the planer.

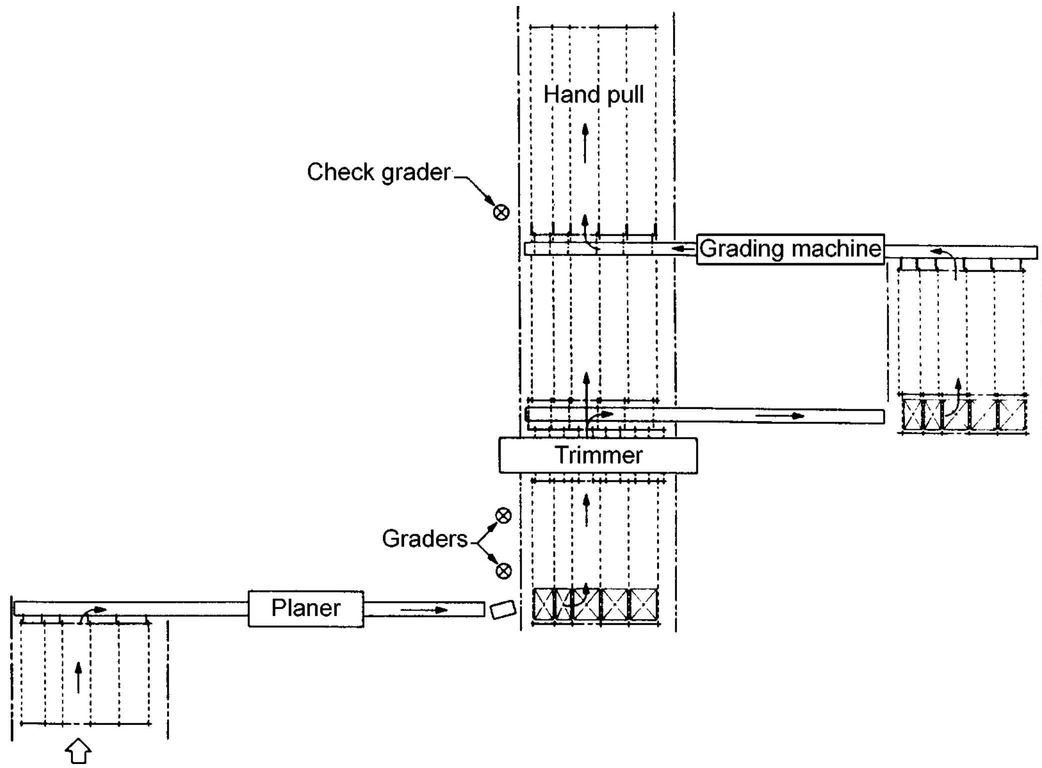

Figure 18—Basic planing mill arrangement for machine grading. Visual graders designate pieces to be routed through grading machine. Check grader follows machine grading and trimming operation to assure correct grade output. Only a portion of lumber normally passes through grading machine.

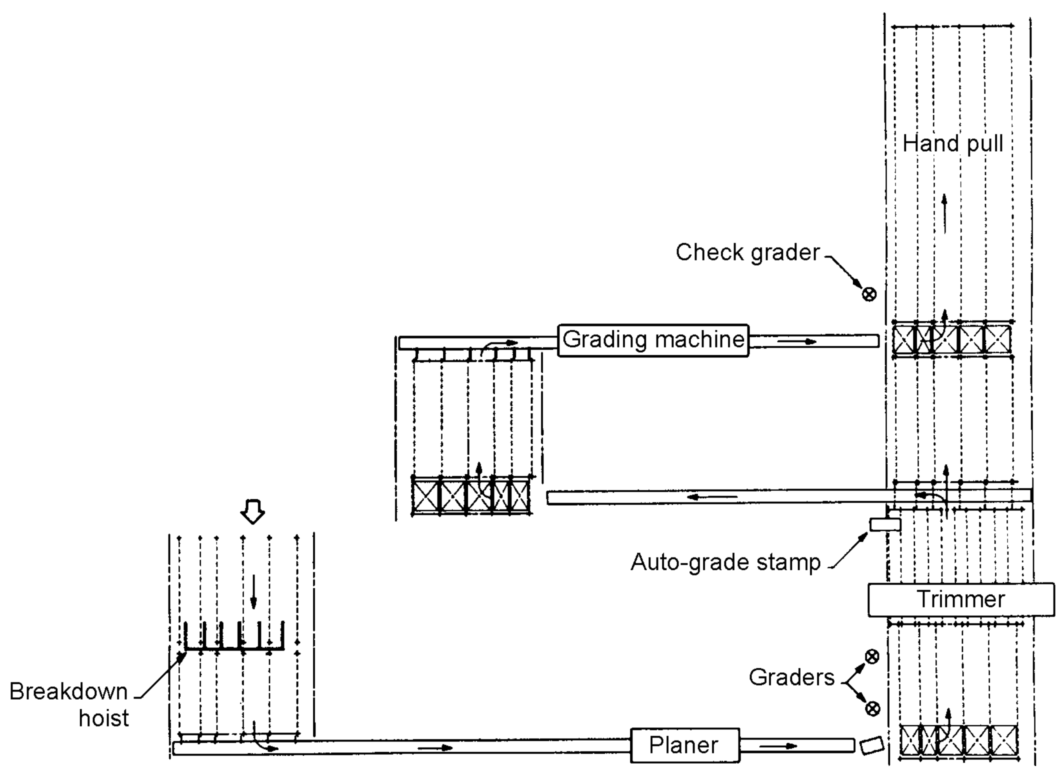

Figure 19—Mill grading arrangement modified from that of Figure 28 to incorporate automatic grading–trimming station that also controls lumber to be routed to grading machine.

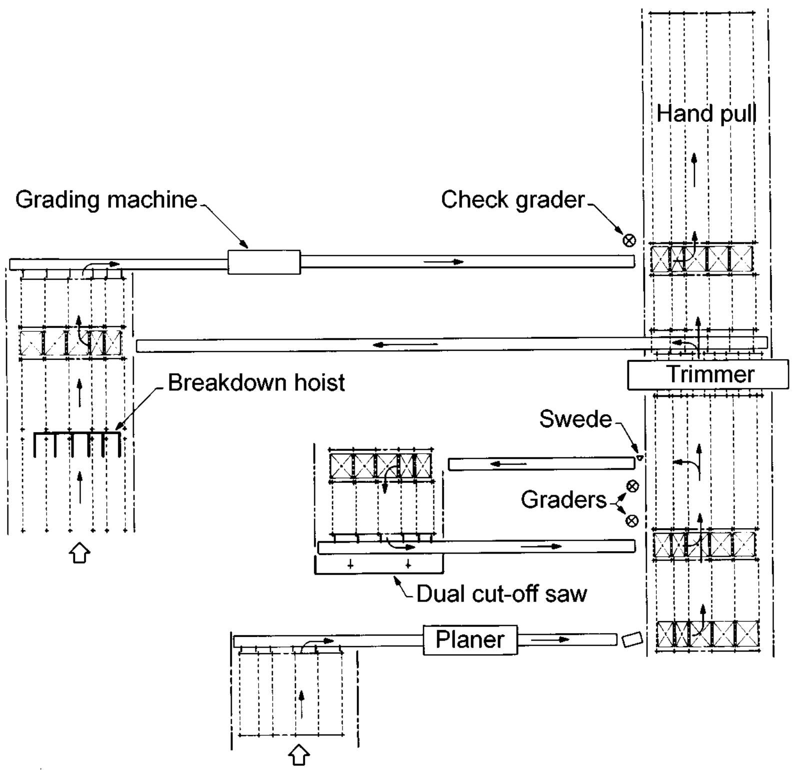

Figure 20—Planing mill arrangement in conjunction with grading machine. Graders can use cut-off saw to upgrade lumber prior to final visual or machine grading. Arrangement includes separate breakdown hoist that permits machine grading independent of standard planing–grading–trimming operation.

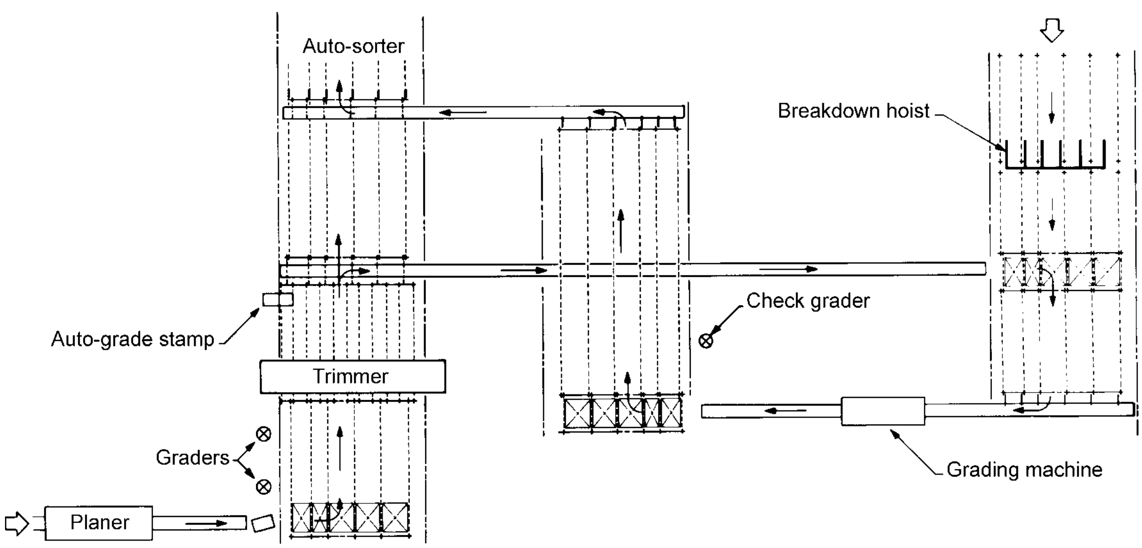

Figure 21—Grading operation in conjunction with automatic grading, trimming, and sorting. Separate breakdown hoist adds flexibility to installation.

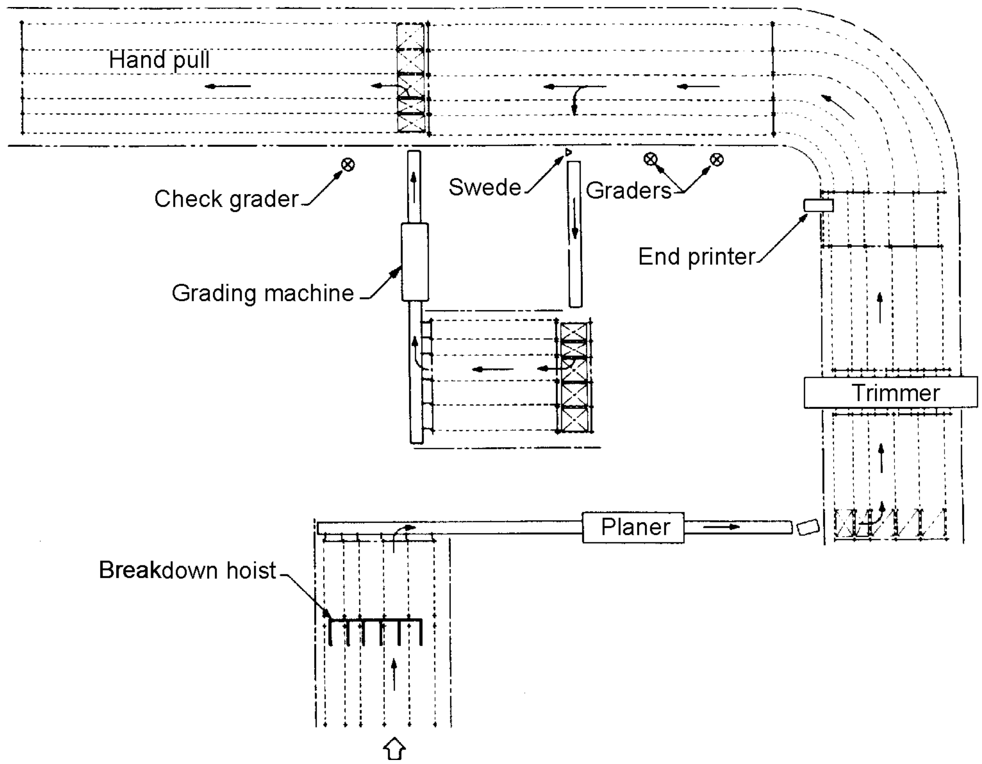

Figure 22—Planing mill arrangement in which graders hand-select pieces to be routed by swede to grading machine.

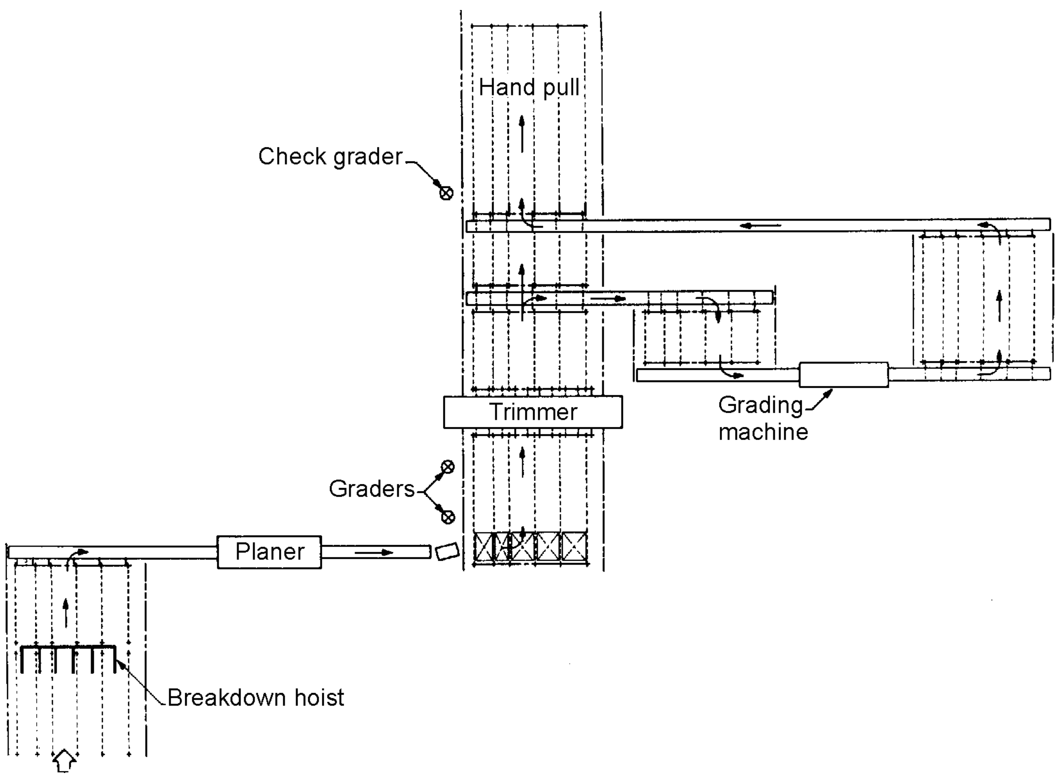

Figure 23—Grading arrangement illustrating variation in equipment for routing lumber from dry chain through grading machine and back to check grader.

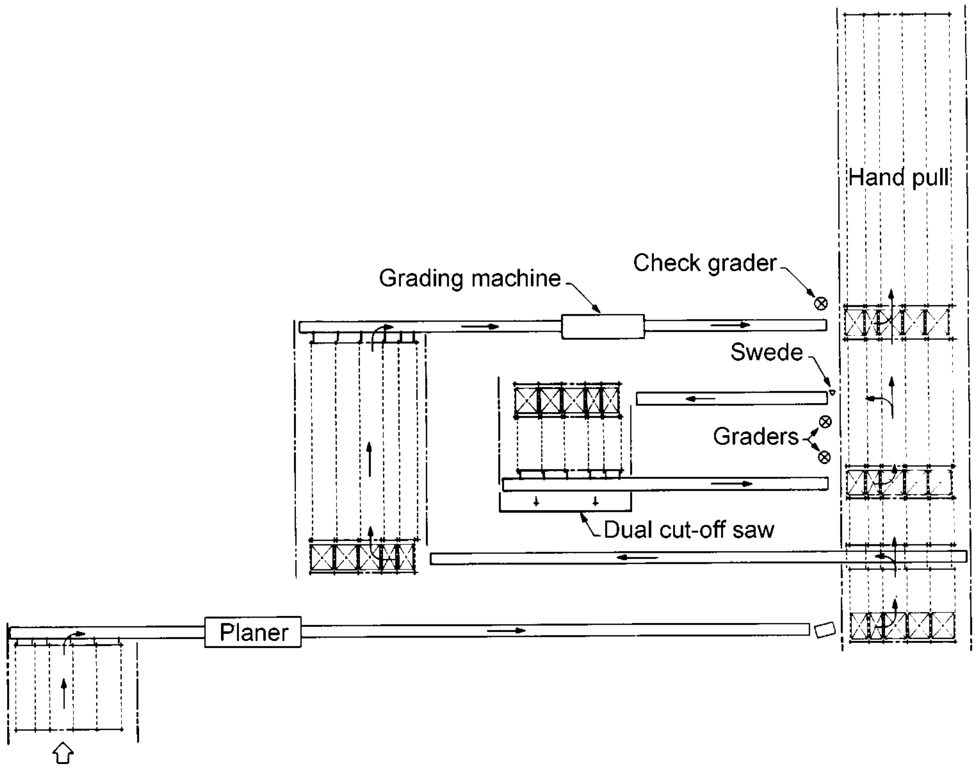

Figure 24—Planing–grading operation in which all trimming is handled by dual a cut-off saw.

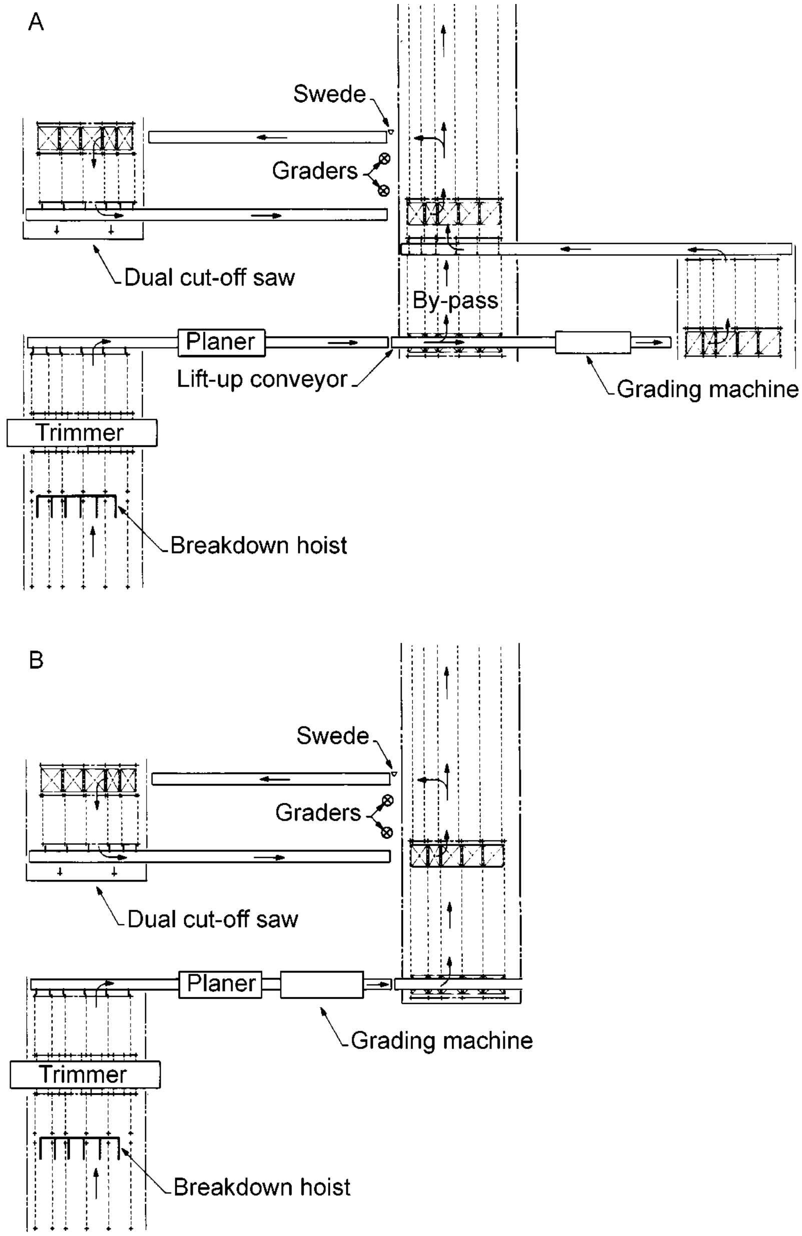

Figure 25—Planing mill arrangement in which all lumber is trimmed before planing and passed through the grading machine as standard procedure. The by-pass (A) permits mill operation with visual grading if the grading machine is out of operation or is not needed. Part B illustrates close coupling to the planer.