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Machine Grading of Lumber

Practical Concerns for Lumber Producers

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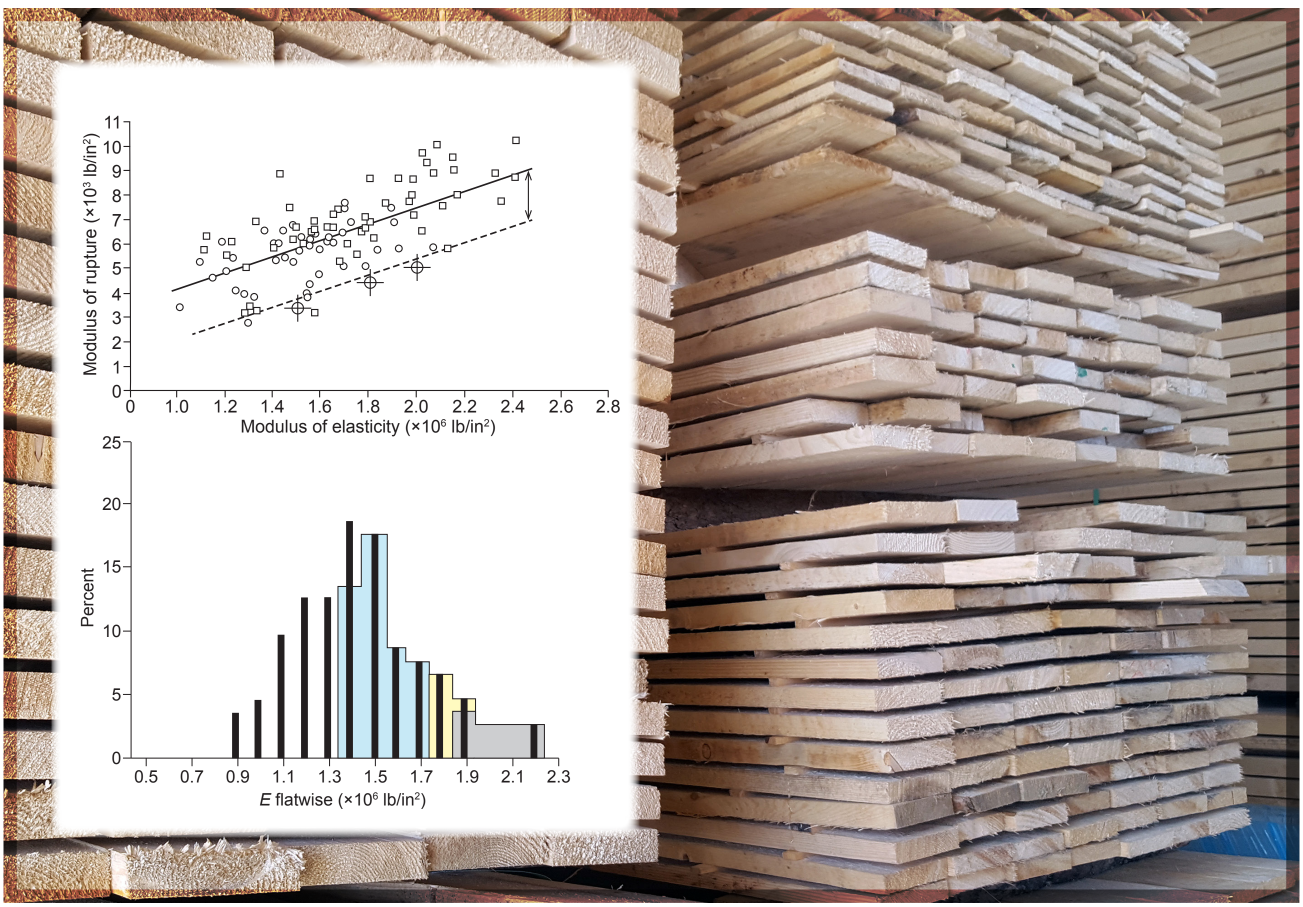

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Abstract

Machine lumber grading has been applied in commercial operations in North America since before 1963, and research has shown that machine grading can improve the efficient use of wood. However, industry had been reluctant to apply research findings without clear evidence that the change from visual to machine grading would be a profitable one. Since 2000, when the most recent version (FPL-GTR-7) of this report was published, new equipment, production scenarios, forest resource changes, and other issues have arisen, resulting in the need for another update. This new report provides key access to American Lumber Standard Committee information including the Machine Graded Lumber Policy and current approved equipment to help mill managers assess the feasibility of machine grading for their products. The first part of this report discusses principles of using machine grading to assign properties. The second part presents methods of machine-graded lumber yield assessment. The final part discusses mill mechanical analysis and cost analysis.

Keywords: Machine grading, machine stress rating (MSR), machine evaluated lumber (MEL), grade yield, visual grading, machine visual grading (MVG), regulatory acceptance, lumber, nondestructive evaluation (NDE)

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Preface

Machine Grading of Lumber—Practical Concerns for Lumber Producers was published by the USDA Forest Service, Forest Products Laboratory, in 2000 as General Technical Report FPL–GTR–7, an updated edition of a 1977 report by the same number. Since 2000, new equipment, production scenarios, forest resource changes, and other issues have arisen, resulting in the need to update the report for 2020. This edition replaces the 2000 FPL–GTR–7, *Machine Grading of Lumber—Practical Concerns for Lumber Producers*, by William L. Galligan and Kent A. McDonald, and the 1977 FPL–GTR–7, *Machine Stress Rating—Practical Concerns for Lumber Producers*, by William L. Galligan, Delos V. Snodgrass, and Gerald W. Crow.

The contents, including the general background to grading, principles of assessing grade yield, and diagrams of mill lumber flow, generally 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 laminated lumber.

To reflect the broadening use of grading with machines in North America, the original title of has been generalized to *Machine Grading of Lumber* to acknowledge that machines are used for E-rating, "stress" grading, and visual grading. In addition, the text is limited to dimension lumber, so 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 North America is not addressed.

When the original FPL–GTR–7 was released in 1977, grading machines had been in use for only about 14 years and major areas of North America had no installations. Machine stress rated (MSR) and machine evaluated lumber (MEL) are the two types of machine-graded lumber produced in North America under the auspices of the American Lumber Standard Committee (ALSC). The ALSC maintains the American Softwood Lumber Standard Voluntary Product Standard PS 20, published by the National Institute for Standards and Technology, and in accordance with PS 20 administers an accreditation program for the grade marking of lumber produced under that system. The American Lumber Standard (ALS) is an integral part of the lumber industry and provides the basis for acceptance of lumber and design values for lumber by building codes throughout the United States. The ALSC is the guiding constituent committee; therefore, the ALS Board of Review is a certification and accreditation board.

With regard to machine-graded lumber, the Machine Graded Lumber Policy of the ALSC sets forth the procedures for grade marking of machine-graded lumber conforming to the American Softwood Lumber Standard PS 20. The policy also includes requirements specific to the machine-graded lumber process and to the approval of the machines. The current lumber policy and list of machines is available at http://www.alsc.org/untreated_machinegraded_mod.htm.

Over the years, a number of descriptive terms have been used in commercial machine grading. To make the necessary additions and modifications to update FPL–GTR–7 as simply as possible without rewriting the document, the terms mechanical grading and 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 laminated grades sorted by machine for stiffness.

Updates on recent developments, including the development and use of acoustic-based machine grading equipment, are included. Further, there has been the advent and adoption of machinery that uses a multitude of sensors and computers to effectively visually grade lumber. These machine visual grading (MVG) systems can replace human visual graders, but mills must continue to maintain a qualified and certified human lumber grader. A new section has been added to this handbook to introduce MVG systems. For more information on the capacity and implementation of MVG systems, it is suggested that users contact the lumber grading and quality assurance organizations and equipment manufacturers.

Finally, a recent publication provides significant, additional information and detail on machine grading of lumber. The *Nondestructive Evaluation of Wood, Second Edition* (General Technical Report FPL-GTR-238) was published by the Forest Products Laboratory in 2015. Chapter 11, "Machine Grading Lumber," offers additional information that should be reviewed by all organizations operating or considering expansion into machine grading of lumber.

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

SI Conversion Factors

Inch–pound unit	Conversion factor	SI unit
inch (in.)	25.40	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)	16.00	kilogram/cubic meter (kg/m^3)
pound/square inch (lb/in^2)	6.895	kilopascal (kPa)
acre	0.4047	hectare (ha)

Acknowledgments

Special recognition is given to William L. Galligan, Delos V. Snodgrass, and Gerald W. Crow, authors of the original FPL–GTR–7, *Machine Stress Rating—Practical Concerns for Lumber Producers*, which was published in 1977. Special recognition is also given to William L. Galligan and Kent A. McDonald, authors of the revised FPL–GTR–7, *Machine Grading of Lumber—Practical Concerns for Lumber Producers*, published in 2000. The authors acknowledge William "Bill" L. Galligan (Private Consultant, Keizer, Oregon, USA) for his contributions to this update and his technical leadership in the development of structural lumber grading technologies. Bill has been a driving force in developing science-based grading procedures and in deriving allowable properties for structural lumber. He was one of the original authors of the 1977 publication. His review and comments on the manuscript were greatly appreciated. We also acknowledge the technical review provided by Don DeVisser, a recently retired West Coast Lumber Inspection Bureau Executive Vice President with a long career in the lumber grading industry, for his valuable comments. The authors thank Dr. Christopher Adam Senalik (Research General Engineer, USDA Forest Service, Forest Products Laboratory) and Dr. Xiping Wang (Forest Products Technologist, USDA Forest Service Forest Products Laboratory) for their technical reviews, thorough edits, comments, and suggestions that improved earlier versions of this report. Thanks to Julie Blankenburg (Supervisory Librarian, USDA Forest Service, National Forest Service Library, Forest Products Laboratory) for her help with data from the Big Book Random Lengths selected issues and years. Finally, we thank Dr. Tâmara Suely Filgueira Amorim França, Assistant Professor in the Department of Sustainable Bioproducts and Forest and Wildlife Research Center (FWRC) at Mississippi State University for her work in data collection, review, and reporting.

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Introduction

Stress grading for structural lumber is not new. Although visual stress grading has been used for over a century, the concept of stress grading with the assistance of a machine has been applied commercially in only the past five decades. Although humans or machines still visually grade most structural lumber in North America, the volume of machine stress rated (MSR) or machine evaluated (MEL) machine-graded lumber is increasing. Additionally, MSR or MEL technology coupled with machine visual grading (MVG) technology is increasing, as described in the "Development of Machine Visual Grading" section of this handbook.

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 mill operation. Because competitors may be using machine grading, the manager continues to search for ways to update an operation while producing a profit and maintaining or improving the quality of the product. Alternatively, 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 handbook 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 (FPL), 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 (the supply of wood logs to a mill) more efficiently. The most significant recent change was in 2020 as American Lumber Standard (ALS) PS 20–20 came into effect (NIST 2020). This product standard incorporated several features, including the assignment of green and dry sizes to accommodate shrinkage of green lumber in place. Under PS 20–20, a National Grading Rule was written that prescribed uniform grading features for the same dimension grades of all species.

Another 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 2019). The current versions of these standards are ASTM D1990-19 and ASTM D4761-19 (ASTM 2019).

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 handbook deals primarily with machine grading, note that the application of machine grading has always been measured and considered against a background of human visual grading practice and tradition.

Development of Machine Visual Grading

In 1998, in a paper presented at the Scan Pro Conference, Kline et al. (1998) predicted that automatic visual lumber grading machines would be installed in sawmills within two years:

> Within the next two years, the lumber manufacturing industry will see some of the first installations of automatic lumber grading systems. These systems will involve complicated mechanisms including cameras, lights, lasers, X-rays, computers, electronics, and other devices necessary to identify lumber grading features. Large and sophisticated computer software will be needed to process the volume of information generated by the scanning hardware. The resulting “digital map” of lumber grading features outputted by the software will be used to automatically sort and grade lumber according to standard grading rules (e.g. Northeastern Lumber Manufacturers Association (NeLMA), Redwood Inspection Service (RIS), Southern Pine Inspection Bureau (SPIB), Pacific Lumber Inspection Bureau (PLIB)/West Coast Lumber Inspection Bureau (WCLIB), Western Wood Products Association (WWPA), National Lumber Grades Authority (NLGA), National Hardwood Lumber Association (NHLA), etc.). However, this data can also provide a potential wealth of information to dramatically reduce costs and increase value recovery by creating a more intelligent, more adaptable manufacturing system. (Kline et al. 1998)

Machines that can visually grade lumber and literally replace human lumber graders have been in development for more than a decade. There were many issues with the early machines; these included hairline cracks, “blonde knots,” and worm holes, which can be detected by a human grader but are often not recognized by a camera-based grading machine (Huang 2011). The processing power of computers and the addition of multiprocessors coupled with a variety of sensors have resulted in machines that can determine visual grades with accuracy. Visual grading machines do not suffer from fatigue or other issues that limit human productivity. However, visual grading machines do not completely eliminate visual graders at a mill, because certified graders are still needed to ensure that machines are grading correctly. A visual grading machine can determine defects present in each board, determine alternative pieces that could be produced given trim options, and select the best option based on current market prices. Newer systems can accept input from stress grading machines, evaluate machine stress grades concurrently with visual grades, and select the highest value alternative. Each piece of MSR/MEL lumber must meet the minimum requirements of the No. 2 visual grade. The MVG system will send trim instructions to the trim saw, grade-printing instructions to a lumber stamp printer, and bin numbers to the drop sorter. Some MVG machines operate in-line with a planer, whereas others operate with the lumber just ahead of the trim saw in transverse. Although the machine can perform an analysis of MVG technology coupled with MSR technology, the architecture of the MSR technology could affect lumber strength values, resulting in product economic value variability. Machines can determine modulus of elasticity (E or MOE) using a transverse wave vibration method and evaluate the entire board with a single stiffness number value (such as 1.5E, 1.6E, …). The MSR machines that determine E at intervals along each board may provide information that the MVG machine uses to significantly change trimming decisions and resultant product (lumber) value. For more information on the capacity and implementation of MVG systems, readers should contact lumber grading and quality assurance organizations and equipment manufacturers.

History of Machine Grading

Machine stress grading was founded on nondestructive testing principles that had been known since before 1963. An example is the demonstration of the fundamental relationships published by Senft et al. (1962), in which the usefulness of E to predict modulus of rupture (MR, now commonly referred to as MOR) was suggested. This, in fact, was the grading basis at that time under exploration for mechanical grading at Potlatch Corporation (Lewiston, Idaho, USA) and the Western Pine Association (Portland, Oregon, USA) (McKean and Hoyle 1964).

Early development of machine lumber grading was marked by worldwide involvement and a commitment of Federal, State, and commercial funding. A 1968 compilation of research and development efforts estimated an accumulated 36 years of lumber-related research at seven national research laboratories worldwide between 1961 and 1968, 28 years at U.S universities, 15 years between Potlatch Corporation, Inc., and the Western Pine Association (late 1950s and early 1960s), 13 years among five machinery companies (Galligan and Moyer 1968) and internationally by 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. Several of these organizations produced commercial grading machines 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 initially, 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; therefore, poor mill operation and machine grading could not exist side by side. Similarly, 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 introduction of machine grading inspired research worldwide in both the fundamental principles of machine grading and their extension to grading criteria and commercial applications.

Early users of stress 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 stress 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, including human visually graded, machine visually graded, and mechanically graded (ALSC 2015).

The past 35 years of machine grading have highlighted that the process coexists with visual grading primarily because of favorable grade yield to the producing mill. Although the use of machine grading is accompanied by design advantages for some final products, the process is principally employed to develop grades with strength values 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 Hemlock–Fir and Spruce–Pine–Fir, from which highly competitive grades can be derived (Table 1). Table 1 shows the MSR production

Table 1—Total machine-stress-rated (MSR) production volume by species of graded lumber from 1997 to 2018 in North America[a]

Species[b]	Production volume (million board feet) by year																					
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
DFL	134.3	176.6	159.0	147.0	146.7	147.7	162.9	173.9	160.8	133.6	77.1	89.4	64.7	102.3	96.7	120.0	162.1	149.6	185.9	185.9	191.9	217.8
HF	60.5	66.7	67.0	57.0	63.9	62.6	56.2	60.7	57.4	59.2	34.8	35.4	14.2	13.4	19.0	12.4	12.2	11.9	11.9	11.9	13.4	10.8
SYP	138.9	154.1	201.1	185.7	226.6	271.1	290.7	276.8	347.1	279.5	199.2	181.0	123.5	133.9	149.4	278.2	292.4	318.7	337.7	337.7	475.8	568.3
SPF	758.1	889.4	954.7	1,284.5	1,229.7	1,492.4	1,497.9	1,664.6	1,810.8	1,720.9	1,056.6	982.8	847.7	833.8	781.5	787.4	946.6	824.9	826.2	826.2	861.6	795.4
Total	1,091.8	1,286.8	1,381.8	1,674.2	1,666.9	1,973.8	2,007.7	2,176.0	2,376.1	2,193.2	1,367.7	1,288.6	1,050.1	1,083.4	1,046.6	1,165.7	1,357.0	1,352.0	1,362.0	1,358.0	1,543.0	1,592.3

[a]Not all mills report or are members of the MSR Lumber Producers Council organization, but these data still provide a useful overview.
[b]Species classification: DFL, Douglas Fir–Larch; HF, Hemlock–Fir; SYP, Southern Yellow Pine; SPF, Spruce–Pine–Fir.

(million board feet) for Douglas Fir–Larch (DFL), Hemlock–Fir (HF), Spruce–Pine–Fir (SPF), and Southern Yellow Pine (SYP) from 1997 to 2018 (MSR Lumber Producers Council 2019).

This handbook is limited to practices in the United States and Canada, with an emphasis on lumber grading machines approved by the ALSC Board of Review (ALSC 2020). Machine grading developments in other parts of the world have different characteristics because of industry custom, governmental regulation, and commercial requirements. Early overviews of developments in other countries are found in Hoyle (1970). Galligan et al. (1986) summarizes early, important international research on machine lumber grading. Ross and Wang (2012) provide a 50-year collection of papers from the Nondestructive Testing and Evaluation of Wood Symposium series; the publication includes a brief history of the symposium series, summaries of each symposium, and searchable electronic copies of each symposium proceedings. The *Wood Handbook—Wood as an Engineering Material* (Forest Products Laboratory 2010) is also highly significant.

Implementation of commercial nondestructive evaluation (NDE) devices for lumber grading hinged on both technological and commercial feasibility. From the very beginning of NDE for lumber grading, these factors have been the subject of study and debate (Galligan and Courteau 1965). The technology of machine lumber grading will be discussed first based on two commercial machine-based predictors of strength—modulus of elasticity (MOE) and density.

Development of Stiffness-Based Grading Machines

Two grading machines were responsible for the early acceptance of mechanical grading in the United States and Canada—the Continuous Lumber Tester (C-L-T) and Stress-O-Matic (SOM). Commercial models of both machines were finalized by machinery firms. Although output from both C-L-T and SOM was based on stiffness measurement, the operating concepts were different. Lumber passing through the C-L-T was bent flatwise, first in one direction and then the other. The lumber followed a prescribed radius, and an output was based on resistance to the curvature as measured with two electronic load cells, one for each bend orientation. The loading could be visualized as fixed ends and a center point load measurement. Many samples (load signals) were taken along the length of the piece. The computer then processed a series of deflection measurements to produce a proportional "average" stiffness along the piece and a value corresponding to the lowest stiffness detected along the cross section. A series of average deflection measurement outputs could be calibrated to correspond to a static test value, keeping in mind that the machine measurement system was not exactly duplicated by any standardized test. The stiffness of the ends of the piece was not measured, because gripping the ends reduced the test length. The same is true in static bending according to ASTM standards. Therefore, a question remains about whether this factor could have any significant effect on the average stiffness of the piece. The C-L-T was developed for dimension lumber of approximately 1.50 in. thick up to 12.00 in. wide; therefore, only moderate adjustment for thickness could be accommodated. These early machines were adjustable in speed; common operation was approximately 700 to 1,000 ft/min.

The Potlatch Corporation (Lewiston, Idaho, USA) conducted research and development for the C-L-T, and the Western Pine Association (Portland, Oregon, USA) developed the concepts behind the SOM. The SOM also bent lumber in the flatwise orientation; however, it was loaded in only in one direction, with a third-point load on a total span of 48.00 in. This was principally a mechanical rather than electrical device for characterization of stiffness sorts. It imposed a fixed load applied on the piece as it traversed the machine. If the piece deflected beyond a fixed load limit that corresponds to a stiffness threshold, the load was reduced (that is, another lower measurement was then set). The load reduction proceeded until the deflection limit was not reached. That last load level determined the stiffness sort for the piece, essentially estimating the lowest stiffness of the piece. The choice of load levels set the number of grade sorts. A maximum speed of about 600 ft/min was obtained. This placed the machine in smaller mills or off-line with production speed planers. The SOM was designed for lumber not exceeding approximately 2.50 in. thick. Galligan et al. (1977) summarized capabilities of early U.S. and foreign grading machines.

In addition to the C-L-T and SOM, one machine that has been in relatively constant use in North America since the 1960s is the E-Computer. The E-Computer is a transverse vibration system that measures stiffness from the fundamental frequency of the flatwise vibration of a piece of lumber supported at the ends. One advantage of this system is the diversity of piece thicknesses that can be accommodated. The E-Computer is often thought of as only a research or survey tool. However, it has been in commercial use for sorting structural stock for cooling towers (Ross 2015). In addition, for several years, the E-Computer has been the production line grading machine for several producers, grading dimension (nominal 2-in.) lumber destined for trusses or laminated beam construction (Ross 2015). This system has low piece throughput, measured in pieces per minute, depending on the material handling requirements of the installation. In fact, the use of transverse vibration is the only NDE technique guided through a consensus standard, ASTM D6874-12, *Standard Test Methods for Nondestructive Evaluation of Wood-Based Flexural Members Using Transverse Vibration* (ASTM 2019).

Advances in all segments of mechanical and electronic technology have greatly benefited mechanical grading. Early electronic "1960s quirks" disappeared with the advent of solid-state systems. Feedback to the operator and clarity of instruction has kept pace. Serious temperature effects that were poorly understood and not controlled in early operation are now better understood and controlled where possible. All machines now rely on computer control and output. Most modern machines focus on dimension lumber; however, they have different throughput capabilities. Consequently, some machines continue to focus on high-speed planer mill operation, even exceeding 2,000 ft/min, whereas others are optimized for lower planer speeds or offline applications such as grading laminated stock. Lumber producers that focus on large markets, such as lumber for metal-plate-connected trusses, often select a high capacity machine to match planer capability. Machines of more limited capacity are well suited for operations that may focus on a limited number of grades and/or sizes.

In addition to machines that bend lumber to measure stiffness, other machines use dynamic measurements, including transverse vibration and longitudinal or "stress wave" propagation. These developments are based on scientific concepts first explored and proven in the 1960s at Washington State University (WSU). During the 1960s–1970s, WSU conducted many field trials to demonstrate and evaluate early prototypes of both stress wave and transverse vibration machines. Collaborators included the Western Canadian Laboratory (Vancouver, BC, Canada); BC Hydro (Vancouver, BC, Canada); Western Pine Association (Portland, Oregon, USA); West Coast Lumber Inspection Bureau (WCLIB) and the Western Wood Products Association (Portland, Oregon, USA); Oregon State University (Corvallis, Oregon, USA); Metriguard, Inc. (Pullman, Washington, USA); and the USDA Forest Products Laboratory (Madison, Wisconsin, USA). Wood products tested included structural lumber, proprietary structural members, laminated lumber, and laminated beams. The WSU–Metriguard–FPL collaboration resulted in a prototype longitudinal stress-wave-based lumber grading machine using microprocessors to control the testing and analysis (Logan and Kreager 1975). These field trials provided basic experience with commercial wood products, established the viability of the testing concepts, and helped spur similar work in other laboratories and machinery companies in the United States, Canada, and many other countries.

Development of Density-Based Grading Machines

Early development of a commercial density-based grading system was conducted in the mid- to late 1980s. Weyerhaeuser filed a patent in 1988 (issued in 1990) for a method to estimate the strength or stiffness of a piece of wood by measuring its longitudinal density profile. Initial development by Weyerhaeuser involved the use of gamma ray absorption to measure density and generate density profiles. As development progressed, the favored radiation source moved toward X-rays, which were found to be more suitable for commercial installations (Schajer 2001). The X-rays are similar to those used for baggage inspection in airports, allowing the machines to be classified as "Cabinet X-ray Machines." In 1992, Weyerhaeuser licensed their density-based technology to CAE–Newnes (Salmon Arm, BC, Canada), a commercial equipment manufacturer. The first commercial prototype was installed the following year in a lumber mill in southeastern United States.

CAE–Newnes and Weyerhaeuser continued to participate in a cooperative development project, and the first commercial X-ray Lumber Gauge (XLG) was built and installed in 1993. One advantage of this concept was the capability to scan the entire board from end to end. This capability eliminated the need to apply additional visual restrictions to the ends of the pieces as is common with stiffness-based machines. With its noncontact methodology, the XLG is capable of processing pieces as short as 4 ft and can operate with line speeds of greater than 2,000 ft/min. Its footprint of 8 by 8 ft generally allows easy inline installation or retrofit directly behind existing planers. The XLG is designed to process 2 by 3 to 2 by 12 dimension lumber. Both the ALS Committee and the Canadian Lumber Standards Accreditation Board accept the XLG as an approved mechanical grading machine.

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 laminated lumber because they are based on mechanical grading to achieve a long span, flatwise measurement of 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 technologies used for machine stress grading, are not "stress" grades. This is 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 (glulam) 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.

Approved ALSC Machine Grading

A mill planning to produce machine-graded lumber under the ALS using bending, transverse vibration, longitudinal stress wave (acoustic), or density technologies must utilize an approved grading machine. These machines are approved under the ALSC through the application to and supervision of a sponsoring certified grading agency. The criterion for approval is that the machine demonstrates the ability to segregate lumber in accordance with the measurement system employed, such as stiffness or density measurement. The evidence provided shall include determination of measurement accuracy, including appropriate statistical analysis, and is relative to an accepted consensus standard. Information listing the manufacturer's recommended operational limits is required, including information on machine measurement repeatability, variability, and recommended limits for the machine environment, such as temperature, operational speed, and humidity, as well as lumber conditions, such as temperature, moisture content, and warp.

Demonstration of the relationship between the measurements made by the machine system and design properties is not an integral part of ALSC approval of the machine. Requirements for this latter step are part of the machine qualification conducted on lumber of the candidate grades from the producing mill after installation and are specified by the operations manual of the ALS-approved agency. This qualification step not only includes the ability of the machine to make the claimed measurements but also incorporates agency-required visual criteria and specific tests, the influence of grade choices on sampling and test results, and mill operating variables, such as sawing patterns and lumber dryness.

Detailed specifications for machine approval, agency accreditation, qualification procedures for a mill or facility by an agency, agency requirements for mill quality control, residual production, and ALSC monitoring of agencies are provided in the ALSC machine-graded lumber policy (App. A) (ALSC 2020). Approved lumber grading machines operating based on stiffness and density measurements by ALSC are listed in Appendix B. The ALSC Board of Review identifies operation limitations for this equipment. Current information and limitations can be accessed at the ASLC webpage (http://www.alsc.org/).

Machine-Graded Lumber Market Development

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 was produced in 1996, with the majority being 2 by 4 and 2 by 6 lumber for metal plate trusses (MSR Lumber Producers Council 1996). (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.) Recent production values reported by the MSR Lumber Producers Council (2019) show a range of production values from 1997 to 2018. The MSR production peaked at over 2 billion board feet during strong construction markets in 2004 to 2006, with a significant decline of over 50% during the recession of 2007 to 2012. Recently, production growth has increased, but is still below peak levels. Table 1 shows total MSR production values by volume of species from 1997 to 2018. Table 2 shows total MSR production volume by size of graded lumber from 1997 to 2018 in North America. Table 3 shows total MSR production volume by grade of graded lumber from 1997 to 2018 in North America.

Table 4 shows the number of sawmills that use visual grading and machine grading. Examination of the data over the 17-year period shows from no growth to a slight reduction in the use of machine grading systems from 2004 to 2020 in the U.S. west coast, inland west, and central/east regions. However, in the U.S. south region, the use of this MSR technology has roughly tripled (Table 4). The expansion of machine grading technology in the south began when the fiber stress in bending (F_b) of 2 by 4 lumber decreased from 1,500 to 1,100 lb/in^2 in 2012 (App. C). The number of total mills decreased in all regions from 2004 to 2020 and represents a greater than 45.0% decrease in the total number of mills in operation within the United States.

As a measure to allow mills to enhance southern yellow pine lumber in various markets, the Southern Pine Inspection Bureau (SPIB 2014) increased the number of allowable grades of MSR and MEL significantly. The reduction in visually graded design values coupled with the increase in number of MSR and MEL grades are widely believed to be the major driving force in the dramatic increase in stress grading technology employed by mills in the south from 2012 to 2015. Trends for various western and southern tree species, as well as the MSR lumber production since the 1990s, are also evident. Table 2 shows the MSR lumber production percentage by various lumber sizes from 1997 to 2018. Table 3 also shows MSR lumber production by grade from 1997 to 2018.

Table 2—Total machine-stress-rated (MSR) production volume by size of graded lumber from 1997 to 2018 in North America[a]

	Production volume (million board feet) by year																					
Size	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2×3	33.0	48.2	57.8	116.2	58.5	71.8	83.7	89.7	94.1	78.2	31.4	145.2	126.2	147.4	134.1	119.7	143.2	143.0	129.1	142.4	144.3	139.8
2×4	611.3	810.8	840.0	1,042.1	1,029.3	1,200.2	1,215.6	1,291.5	1,412.4	1,370.5	767.7	671.1	560.5	565.9	528.4	593.4	716.6	662.4	691.6	833.4	796.8	822.1
2×5	2.9	NA	NA	NA	NA	NA	NA	NA	NA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2×6	277.7	319.8	349.9	395.9	433.4	525.4	519.8	588.7	662.6	584.1	420.4	331.5	269.4	265.5	281.6	309.8	348.1	352.3	358.8	386.9	392.4	415.0
2×8	38.5	61.6	68.1	69.9	91.3	108.3	111.3	117.9	116.2	100.6	83.4	77.9	51.1	54.1	49.4	75.2	73.6	102.6	104.8	106.6	121.3	122.4
2×10	13.9	21.5	35.7	31.7	39.5	52.9	56.9	65.9	69.3	46.1	50.0	45.2	31.4	37.4	36.5	46.5	52.8	62.3	58.0	64.8	63.7	67.2
2×12	4.5	8.3	9.3	9.7	10.0	11.6	16.8	17.2	16.5	13.7	14.8	17.8	11.4	13.0	16.5	21.2	22.3	29.0	19.3	23.6	24.2	25.8
Other	110.0	16.7	21.0	NA	NA	NA	NA	NA	NA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	1,092.0	1,287.0	1,381.8	1,674.2	1,666.9	1,973.8	2,007.7	2,176.0	2,376.1	2,193.2	1,367.7	1,288.7	1,050.0	1,083.3	1,046.6	1,165.7	1,356.6	1,351.6	1,361.6	1,557.7	1,542.7	1,592.3

[a]Not all mills report or are members of the MSR Lumber Producers Council organization, but these data still provide a useful overview.

Table 3—Total machine-stress-rated (MSR) production volume by grade of graded lumber from 1997 to 2018 in North America[a]

	Production volume (million board feet) by year																					
MSR grade	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1,350F_b 1.3E	2.8	NA	NA	NA	NA	NA	NA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1,450F_b 1.3E	42.4	53.3	42.3	49.9	45.2	34.0	33.9	NA	23.7	NA	35.4	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1,500F_b 1.4E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.2	5.2	6.0	9.0	9.1	6.9	0.0	0.0	2.4	2.3	1.6
1,650F_b 1.5E	480.0	556.3	596.8	804.8	792.7	962.2	967.3	1,044.1	1,167.8	1,137.4	719.1	642.3	580.2	538.2	535.6	528.3	653.5	584.9	605.6	628.6	646.6	587.8
1,800F_b 1.6E	72.7	64.7	61.0	67.8	74.8	72.3	74.5	95.5	98.4	74.7	27.2	29.0	21.1	45.3	48.4	58.8	82.6	75.6	95.0	105.3	104.9	118.2
1,850F_b 1.7E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	14.1	0.0	0.0	17.0	17.0	17.8	21.2
1,950F_b 1.7E	23.2	35.9	29.0	25.4	41.0	44.8	48.1	41.9	39.1	42.3	24.8	24.9	15.7	19.2	12.7	20.8	30.3	20.7	28.8	31.8	24.6	26.6
2,100F_b 1.8E	219.2	262.1	287.8	365.2	342.1	422.1	419.0	529.7	529.7	473.3	278.6	300.9	230.4	261.2	240.7	266.9	301.9	249.4	245.6	246.5	270.2	265.7
2,250F_b 1.9E	34.4	30.0	34.3	37.3	41.7	53.8	55.1	40.9	29.2	22.5	4.9	7.4	6.2	10.7	3.2	5.4	7.9	12.0	12.7	11.1	9.8	9.4
2,400F_b 2.0E	90.4	123.9	143.3	157.9	184.2	224.7	256.4	291.2	321.1	286.8	220.7	232.9	165.8	176.3	175.7	206.9	214.0	316.4	303.9	346.8	380.7	442.6
2,500F_b 2.1E	3.2	0.0	NA	6.5	8.1	2.4	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2,550F_b 2.1E	3.7	0.0	NA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.2	0.0	0.0	0.0	0.0	0.0
2,700F_b 2.2E	3.8	NA	NA	NA	4.7	8.9	20.7	NA	NA	NA	0.0	1.1	0.8	0.0	0.3	17.6	17.6	22.1	24.0	24.2	30.3	34.4
2,850F_b 2.3E	3.0	NA	NA	3.2	4.8	5.3	7.9	8.9	8.1	8.9	5.5	5.9	3.9	3.5	2.1	13.3	15.4	19.4	15.4	15.8	15.3	15.5
M Grades	NA	NA	83.9	147.3	122.1	142.8	119.5	82.6	140.6	102.4	37.9	35.0	20.7	22.9	18.1	23.5	24.0	5.7	6.1	23.2	40.2	69.3
Other	113.0	160.6	103.3	NA	4.9	NA	NA	41.2	18.4	44.9	13.6	0.0	0.0	0.0	0.0	0.0	0.0	27.5	2.4	0.0	2.4	0.0
Total	1,091.8	1,286.8	1,381.8	1,674.2	1,666.9	1,973.8	2,007.7	2,176.0	2,376.1	2,193.2	1,367.7	1,288.7	1,050.0	1,083.3	1,046.6	1,165.7	1,356.6	1,351.6	1,361.6	1,557.7	1,542.7	1,592.3

[a]Not all mills report or are members of the MSR Lumber Producers Council organization, but these data still provide a useful overview.

Table 4—Mills using visual and machine-stress-rated (MSR) lumber grading technologies, by region and year from 2004 to 2020, within the United States[a]

	U.S. West Coast			U.S. Inland West			U.S. South			U.S. Central/East			
Years	Visual	MSR	Total mills	Visual	MSR	Total mills	Visual	MSR	Total mills	Visual	MSR	Total mills	Total sawmills
2004	87	6	93	104	5	109	262	15	277	82	2	84	563
2005	94	4	98	98	4	102	256	16	272	83	1	84	556
2006	89	4	93	97	4	101	244	15	259	76	1	77	530
2007	89	5	94	92	4	96	232	16	248	74	1	75	513
2008	87	4	91	93	4	97	198	17	215	73	1	74	477
2009	81	4	85	89	4	93	181	18	199	68	1	69	446
2010	78	5	83	74	9	83	162	16	178	63	1	64	408
2011[b]	—	—	—	—	—	—	—	—	—	—	—	—	—
2012	69	5	74	70	5	75	137	32	169	51	0	51	369
2013	67	3	70	70	5	75	127	38	165	49	0	49	359
2014	66	3	69	66	8	74	118	43	161	49	0	49	353
2015	61	3	64	66	5	71	113	44	157	49	0	49	341
2016	54	4	58	67	5	72	100	43	143	45	1	46	319
2017	53	3	56	60	5	65	101	47	148	46	1	47	316
2018	54	3	57	60	5	65	103	46	149	42	1	43	314
2019	55	3	58	58	5	63	103	46	149	43	1	44	314
2020	54	2	56	57	5	62	107	45	152	44	1	45	315

[a]From *Big Book*, Random Lengths, P.O. Box 867, Eugene OR, 97440, selected issues and years.
[b]The Random Lengths *Big Book* was not published in 2011, so no information is available.

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. As noted in a previous section, a second system was introduced in the 1990s for commercial production that uses density as a predictor instead of stiffness (Ziegler 1997). In this handbook, stiffness (E/MOE) will be used to illustrate the mechanically measured predictor variable; however, the illustrations are intended to be generic and apply to the use of density as a predictor. Furthermore, differences in predictive efficiency, and consequently product yield, may vary by choice of predictor as well as by choice of grading equipment and 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. The visual override may be performed by a human grader or MVG technology. Most often, these are stated as limitations on characteristics falling at the edges of the piece. This visual override system began in machine stress rating as the fraction of the cross section and was made part of the grade description. In this handbook, 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 handbook. Nevertheless, these characteristics, if limited, can affect yield, and affected parties are advised to consult with the agency regarding 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 that the use of E as a single predictor of bending strength with lumber data ensures that about 95% of the data will fall above the predicted line. This predicted line is the lower tolerance limit that is used rather than a regression line in Figure 2. Only a small proportion of the pieces fall below the tolerance line; therefore, design values

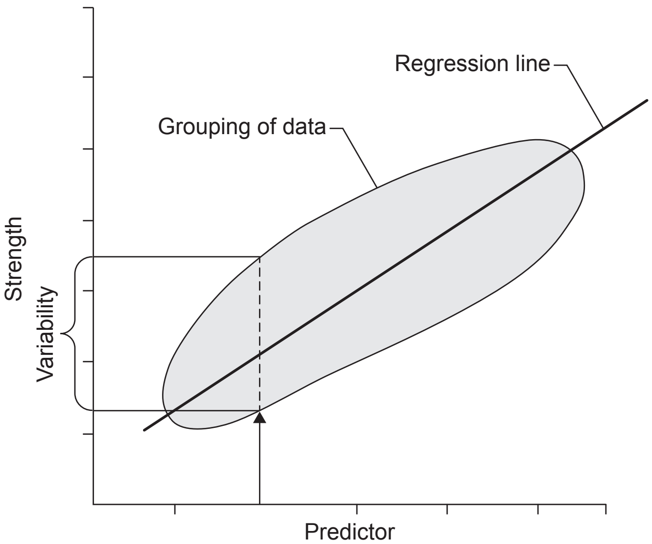

Figure 1—Prediction of strength by regression analysis.

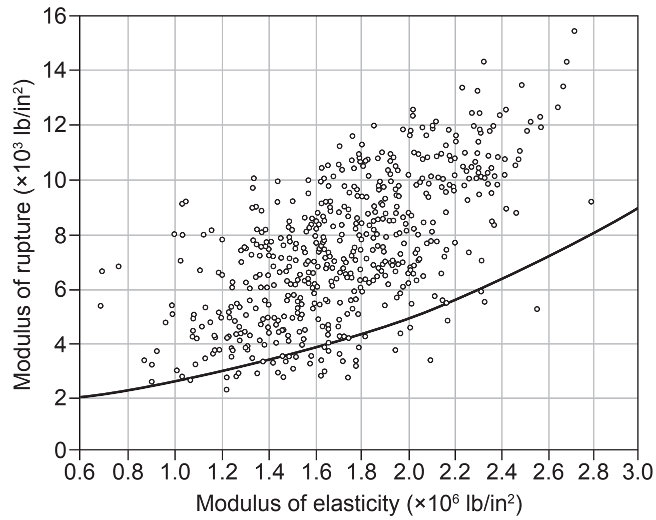

Figure 2—Typical relationship between strength predictor MOE and strength. The tolerance limit ensures that about 95% of the data will fall above the line.

Table 5—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 set from this point based on safety factors and other adjustments. Research continues to seek more efficient predictors of strength properties over time. As noted previously, the two nondestructive predictors currently used in commercial equipment are E and density.

Some characteristics of machine 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 5 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 are placed in the corresponding positions in the table. Although for any one visual grade (for example, No. 1) the visual grade descriptions are the same for all species (such as same knot size, same slope-of-grain requirements), 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 5 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; however, 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 (Table 5).

In contrast with the visual grading system, there are fewer machine grades. This is 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. Although Table 5 illustrates the variety of design values that can result from the species influence in the visual grades, the leftmost column of Table 5 and the table of design values from the 2011 WWPA grading rule (Fig. 3) both illustrate the contrast, a smaller set of common values across species in the machine grades (WWPA 2017, 2011, 2008, 1976). In the past 57+ years of machine grading (since around 1963), however, a more varied array of machine grades has been developed, often because qualification by test has illustrated better 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 and property combinations in an effort to optimize supply of wood logs to a mill.

Because machine 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 (*Tsuga heterophylla*). Visual grading in different mills can result in different stiffness distributions within the same species (Fig. 5; Galligan and Snodgrass 1970). By contrast, machine 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 publication. 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 C, along with nomenclature and performance criteria. Selection criteria for strength test samples are described in Appendix D, and matrix evaluation of machine grades is presented in Appendix E.

MACHINE STRESS-RATED LUMBER
2″ and Less in Thickness
2″ and Wider
Design values in pounds per square inch(2)
Normal Duration of Load

Extreme Fiber Stress in Bending "Fb" (1) Single	Modulus of Elasticity "E"	Tension Parallel to Grain "Ft"	Compression Parallel to Grain "Fc//"
2850	2,300,000	2300	2150
2700	2,200,000	2150	2100
2550	2,100,000	2050	2025
2400	2,000,000	1925	1975
2250	1,900,000	1750	1925
2100	1,800,000	1575	1875
1950	1,700,000	1375	1800
1800	1,600,000	1175	1750
1650	1,500,000	1020	1700
1500	1,400,000	900	1650
1450	1,300,000	800	1625
1350	1,300,000	750	1600
1200	1,200,000	600	1400
900	1,000,000	350	1050

Horizontal Shear (Fv) for all stress levels(3)

Douglas Fir-Larch	= 180
Douglas Fir-South	= 180
Hem-Fir	= 150
Spruce-Pine-Fir (South)	= 135
Western Cedars	= 155
Western Woods	= 135

Compression Perpendicular to Grain (Fc⊥) (3)

Douglas Fir-Larch	= 625
Douglas Fir-South	= 520
Hem-Fir	= 405
Spruce-Pine-Fir (South)	= 335
Western Cedars	= 425
Western Woods	= 335

(1) "Fb" design values are applicable to lumber loaded on edge. When loaded flatwise, the values may be increased by multiplying by the following factors:

Nominal Width (in.)	3″ & less	4″	5″	6″	8″	10″ & wider
Factor	1.00	1.10	1.10	1.15	1.15	1.20

(2) Design Values for grades intermediate between grades shown in the table may be interpolated. Values interpolated shall be rounded to the nearest increment as indicated below:

Modulus of Elasticity (E)	100,000 psi
Fiber Stress in Bending (Fb)	50 psi at 1000 psi and above 25 psi below 1000 psi
Tensile Stress Parallel to Grain (Ft//)	25 psi
Compression Parallel to Grain (Fc//)	25 psi

(3) Compression perpendicular to grain (Fc⊥) and horizontal shear (Fv) values are the same as assigned by ASTM methods to visually graded No. 2 lumber of the appropriate species unless qualified by specific gravity tests. See Section 100.00 through 180.00 for additional information about the use of these values.

Figure 3—Common property values across various species in machine-stress-rated lumber grades as revised in the 2011 WWPA grading rulebook (WWPA 2011, pp. 120, 121). (Tensile Stress Parallel to Grain corrected to Ft//. Compression Parallel to Grain corrected to Fc//.)

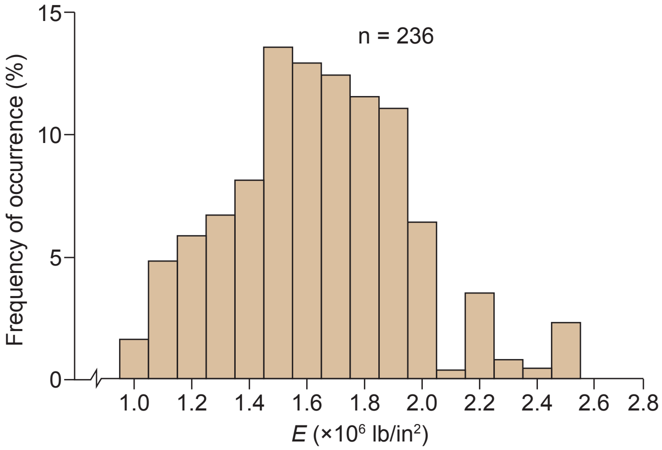

Figure 4—Distribution of *E* in sample of Standard grade western hemlock (*Tsuga heterophylla*).

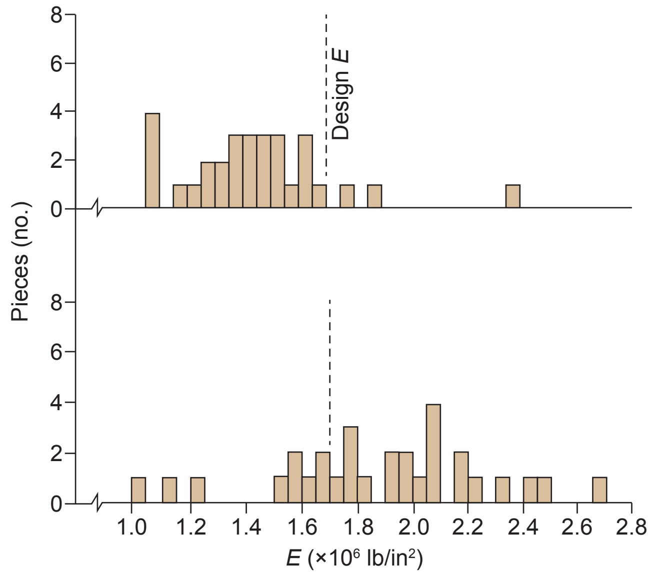

Figure 5—Example of differences in *E* in samples of same grade of lumber graded at two lumber mills.

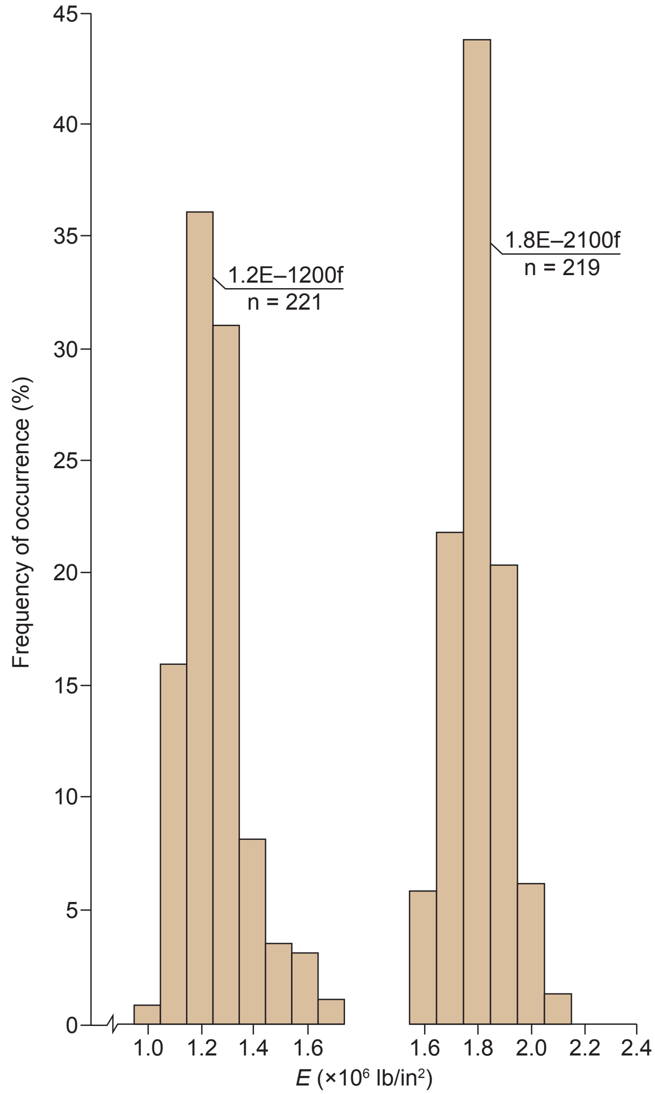

Figure 6—Variability in MOE in two typical machine stress grades.

E-Rated Grading

The E-rated grades for laminated lumber were standardized by the American Institute of Timber Construction (AITC) in the 1980s and recognized under ANSI/AITC A190.1-2012 (APA 2013a) and ANSI/AITC A190.1-2017 (APA 2017). The current title of the standard is ANSI A190.1-2017, *American National Standard for Wood Products—Structural Glued Laminated Timbers* (APA 2017). The WCLIB acquired the AITC glulam design, grading, and certification programs in January 2013 (WCLIB 2020). The American Plywood Association (APA, now called APA–The Engineered Wood Association) replaced AITC as the Secretariat for ANSI standards ANSI/AITC A190.1 and AITC 117. The ANSI/AITC A190.1-2017 was renamed ANSI A190.1-2017, retaining the same title (APA 2017). The AITC 117-2010 was renamed ANSI 117-2010 and more recently ANSI 117-2015, retaining the title, *Standard Specification for Structural Glued Laminated Timber of Softwood Species* (APA 2015, 2013b).

This standard and related reference documents require knot size, 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 laminated lumber, supervisory laminating associations obtain the knot and modulus data by survey of graded lumber. E-rated laminated lumber is distinguished from visually graded laminated 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, ANSI 117-2015 (APA 2015).

The E-rated grading is compatible with MSR and MEL machine grading. The systems can exist simultaneously in a grading operation if the criteria of both systems are maintained. 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 D3737-18e1 (ASTM 2019). Some technologies 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), whereas other manufacturers' technologies measure over a short span but integrate the results over the entire length of the piece. Still various other technologies make one measurement over the entire length of the piece. As a consequence, both the manner in which data are obtained and the manner in which they are analyzed and reported by the device influence the relationship between machine data, specification, and grade yield. For this reason, the output of the device is always 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; therefore, the number and properties vary by species. This limitation is determined by the composition required for laminated beams of current commercial interest and subsequent allowable design values that can be produced with this E-rated lumber. Consequently, E-rated grades are generally not commodity products and are produced after careful marketing discussions with customers, the laminated beam fabricators.

Implementation of Machine Grading

Machine Grading

Most lumber that is machine graded in the United States is graded under the ALS (NIST 2020). As noted, this includes MSR and MEL lumber. Thus, machine-graded lumber has the same legal and procedural backing as does visually grade lumber. 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.

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

Before a machine grading operation is implemented, it must meet certain certification requirements of the supervisory grading agency. 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 MSR and MEL grades produced must be acceptable to engineers, code authorities, and regulatory agencies. To achieve that acceptance, most companies rely largely 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 graded lumber, the grading agency provides the technical and practical data that suggest the capabilities of machine grades for marketing use. These data are reported in design references such as the *National Design Specification for Wood Construction* (AWC 2018, 2015, 2012; AF&PA/AWC 1997), as well as in the grading rules. In addition, the grading agency fields questions on specific design applications: (a) it works with authorities in the code and regulatory areas to secure acceptance of property data, (b) it may seek variances in existing practice to make the grading process compatible with the needs of the mills, and (c) 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 A190.1, the *American National Standard for Wood Products—Structural Glued Laminated Timber* (APA 2017, 2013a). The lumber may also be graded under the supervision of ALS-approved grading agencies. Because 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 numbers of grades of interest are limited; therefore, 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.

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 mean *E* and 5% tolerance limit of *E*.

The laminating industry has also adopted the use of machine 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 the same as though the *E* cut-off were not used. The criteria for mean *E* and 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 A190.1 or the layup rules of ASTM D3737-18e1 for E-rated lumber (ASTM 2019; APA 2017, 2013a).

Current Machine Grading Operations

Domestic Operations

The number of machine grading operations in the United States remained rather constant from the mid-1960s to 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). Recent production values for E-rated lumber were reported by the MSR Lumber Producers Council (2019); Tables 1–4 summarize lumber mill data from 1997 to 2018. For the latest overall lumber information for North American lumber mills, check the Big Book, Random Lengths, P.O. Box 867, Eugene Oregon, 97440, USA (see latest editions).

The primary market for machine-graded lumber is the structural light-framing components industry. The highest strength grades were originally used for specialty trusses such as those manufactured by RedBuilt (Boise, Idaho, USA) (originally known as Trus-Joist Corporation). These grades are now more commonly used for high capacity pitched chord and floor metal plate trusses or flanges in prefabricated wood I-joists. 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 1,650f and 1,800f, are generally sold for metal plate trusses designed for the housing and light industrial markets. Lower grades, such as 1,350f and 1,450f, meet the requirements for shorter span roof trusses and 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 2,400f–2.0E, can be qualified by test from the western true firs (*Abies* spp.); however, the volume generated from these species may preclude specific mills from developing market quantities. Later sections of this handbook explore yield estimation.

As noted previously, the domestic market for E-rated laminated lumber is not commodity driven; rather, E-rated laminated lumber is most often sold directly to the laminator. These grades have been most successful in species classifications, such as Hemlock–Fir, where it is more feasible to produce a beam of 2,400f 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 (*Pseudotsuga menziesii*) or Southern Yellow Pine Group (*Pinus* spp.), 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 laminated grades. Based on analysis of beam requirements using principles of ASTM D3737-18e1 (ASTM 2019), 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.

In North America, the MSR Lumber Producers Council represents the interests of machine rated lumber producers in the manufacturing, marketing, promotion, utilization, and technical aspects of MSR and MEL lumber (MSR Lumber Producers Council 2019). The organization offers membership to lumber producers, equipment manufacturers, suppliers, customers, and professionals. More information about this organization is available at http://www.msrlumber.org.

Foreign Operations and Markets

Although North America has the MSR Lumber Producers Council, a similar entity does not exist for most foreign manufacturers. New Zealand has a much higher production in machine grading, ~90% of structural lumber, according to Peter Carter, Chief Executive Officer of Fibre-gen, Auckland, New Zealand (https://www.fibre-gen.com/about-us). Only limited data are available for production

Table 6—Partial budgeting form for analyzing a change in enterprise operations

Proposed change—Add MVG, MSR, or MEL equipment			
Positive effects	**Value**	**Negative effects**	**Value**
Additional income		Reduced income	
Total additional income		Total reduced income	
Reduced costs		Additional costs	
Total reduced costs		Total additional costs	
Total additional income and reduced costs		Total reduced income and additional costs	
Change in net income = (total additional income and reduced cost) – (total reduced income and additional costs)			

operations in South America, Europe, Asia, or Australia. However, there are a number of European manufacturers of machine grading technologies, which are used by wood products companies to produce machine-graded lumber in these regions and in North America, as qualified through ALSC. Limited volumes of machine-graded lumber are exported from the United States to overseas markets.

Assessment of Production Potential

A company that is contemplating adding machine grading capacity 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 supply resource will produce, but also the grade content and quantity of the residual lumber that will not be machine graded.

The key economic tool to perform this analysis is a partial budget that is well understood by financial institutions. Table 6 shows the general format of a partial budget. A partial budget analysis can be applied to adding any item of technology mentioned in this handbook. In general, a partial budget is a useful format to capture all the changes (positive and negative) associated with adoption of a technology. A partial budget is not an optimized methodology and as such can analyze only the proposed change, but it can determine if the proposed change is the best solution.

Proposed Change: It is imperative that the manager has a clear understanding of exactly what is being proposed. The more alternatives that are analyzed, the better the chance of finding the one that fits best. Each alternative should be analyzed individually.

Additional Income: The proposed change may bring about additional income from a change in product mix. Be aware that it may take time to influence a customer base to effectively capture the value available in an alternative mix.

Reduced Costs: As an example, some technologies, such as MVG, may result in reduced labor for graders because fewer are required.

Reduced Income: Changing the product mix may mean that there is less of a specific grade (possibly #2 visual grade) to produce an income.

Additional Costs: Depending on the technology being evaluated, an additional cost might be needed for QC personnel costs.

Partial budgeting techniques are taught at many universities and are well documented on the internet. Additional details are provided at the USDA Natural Resources Conservation Service (NRCS) website as “Envelope Economics Partial Budgeting” (http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1193223.pdf).

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 economic return favorably or unfavorably, depending on specific production and marketing circumstances. The difficulty of assessing production potential has been a long-standing problem. Hoyle (1970) presented some yield estimates for machine stress grades made in the early 1960s. 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.

A key portion of this discussion is knowledge of the available timber and log supply resource and the associated lumber it produces. With changing silvicultural practices, especially in the U.S. south region, this key knowledge is becoming more difficult to ascertain. A mill may be located in an area with a mixture of plantations and natural stands. In plantation stands, the seedling stock, planting rate per acre, presence of fertilization, herbicide applications, pruning, and thinning regimen can all affect the amount and quality of MSR lumber.

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 grading 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 handbook.

This section is limited to estimating the change in product mix if MSR/MEL machine grading were introduced into a mill currently producing dimension lumber by visual grading. This handbook 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. D), 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 Hemlock–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, as this example illustrates only 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 FPL–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; the mill 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 grades are designated by the recommended design values for the grade in extreme fiber stress in bending (F_b) and modulus of elasticity (MOE or E) or by a name, such as M–23, to which the design values are associated. For example, the grade designation 1,650f–1.5E means that 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 C 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 to E-rated grades.

Slight differences in grade combinations, grademarks, and grademarking procedures exist between grading agencies. For uniformity throughout this handbook, the species, grades, and procedures of the Western Wood Products Association (WWPA) form the basis for all illustrations (WWPA 2017, 2011, 2008). If a similar survey is conducted, it is important to apply 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 2017, 2011, 2008). Again, note that this illustration was prepared in 2011; therefore, 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 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. 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. Because that is the basis for this illustrative method and to simplify the following discussion, the concept of 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 7 shows this relationship.

Table 7—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 8—Approximate equivalent edge knot sizes for machine and visual stress grades

Machine stress grades		Visual stress grades	
VQL	Edge knot as fraction of 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 edge characteristic restrictions for machine stress grades are very nearly equal to those applied to certain visual stress grades, as shown in Table 8. 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_b 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.

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

Table 9—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.

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 9. 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 (Table 9). 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 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 graded lumber and machine-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 10 to 12 for visual stress grade, VQL, and machine stress grade categories, respectively.

Tables 10 and 11 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 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 (Standard and Better (Std & Btr)) grades can be machine graded except for that portion of Standard with edge knots larger than half the cross section (Tables 9 and 11).
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 10 and 11).
4. No Utility or Economy lumber is qualified for machine grading (Tables 8, 10, and 11). (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, and species) currently being produced.)

Table 10—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 11—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 12—Interaction of visual grading function (by grader) and grading machine function (by machine) in sorting lumber by machine-stress-rating grade rules

Grading machine function[b]	MSR visual grading function[a]				
	VQL–1	VQL–2	VQL–3	VQL–4	Reject
Higher	Qualified for 2100 F_b and higher grades				
E-classes		Qualified for 1500, 1650, and 1800 F_b grades	Qualified for 1200 F_b and 1350 F_b grades		
Lower				Qualified for 900 F_b grades	Not qualified for MSR grades

[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 12. This is a schematic of Table 7 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 10 to 12 is that any machine grade will contain lumber of any No. 2, No. 1, or Select Structural grades of the visual grading system. In addition, machine grades of the 900F_b 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, and 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 above.

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, and 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 1,650f–1.5E, 2,100f–1.8E, and 2,400f–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 1,650f–1.5E, 2,100f–1.8E, and 2,400f–2.0E 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 for Machine Stress Grading

Once the decision has been made to limit the investigation to 2 by 4’s and three grades (1,650f–1.5E, 2,100f–1.8E, and 2,400f–2.0E), the following questions can be addressed:

1. Which 2 by 4 grades shall be investigated?
2. What quantity of these grades is produced each year?

Review of the machine grading rules (Tables 7 and 12) 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 contains Standard and Construction grades of lumber.

Review of the conclusions from comparing the grading systems (Tables 9 to 11) 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. The 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 the supply of the wood to a mill as variables, the grader assisting in sample selection and analysis should be well acquainted with all alternatives examined.

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.

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 estimations rest on the assumption that the timber resource (the supply of wood to a mill) 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 nonrepresentative 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 during 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 nonrepresentative lot. Consider discarding the suspect data and obtaining new information.

Appendix D 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 require knowledge about the VQL and E of each piece sent to the laboratory. Therefore, each piece

MSR Recovery Estimate – Data Sheet

Size 2x4 Species Hem-Fir Grade Std & Btr

Date 7/10/2020 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.

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 (F_b) that is higher than the fiber stress in bending (F_b) of the lowest machine grade being graded from the same production. Consequently, the simultaneous operation of visual grading and machine

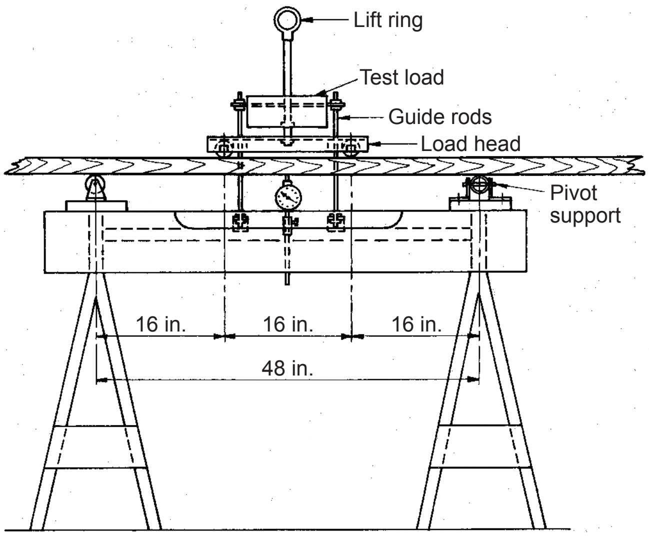

Figure 8—Static tester. This simple mechanical device applies a dead load to a piece of lumber placed flat on a 4-ft span.

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 based on *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 planer mill may be called upon to ensure 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 three to four days with an interval of two to three 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 through down the production line. 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 three to four 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 were 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 13). Utility grade was inspected in the first test run, although this was not necessary. Table 13 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 recovery of VQL–1 and VQL–2 only. For these VQLs, 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 14) and proceed.

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

Table 13—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%			

Table 14—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

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.

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. 10–12). 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 sample. Moisture content was observed to be lower in the second sample and was assumed to be the cause of the higher 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 D describes basic procedures for selecting samples. Grading agency supervision is desirable; therefore, agency procedures may be more specific than the general procedures described in Appendix D. 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

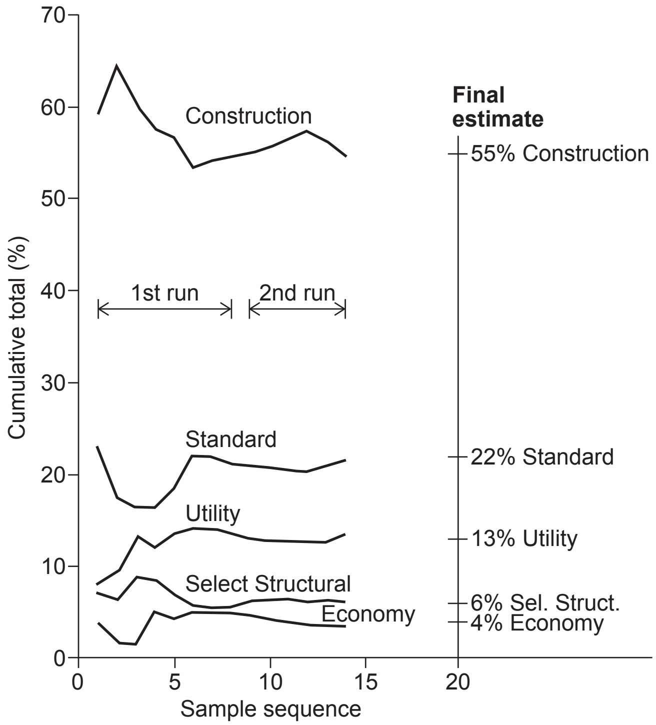

Figure 9—Production of each visual grade estimated by taking sequential 200-piece samples and plotting cumulative total of grades observed.

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 100,000 lb/in^2. This estimates the mean E value required for the grade in question. In Figure 14, the value 2.1 × 1,650 (MOR = 3,465) intersects with the 5% line at 1.42E. After adding 100,000 lb/in^2 (0.10E), an estimate of mean grade E for the 1,650F_b grade will be 1.52. Note that this is slightly greater than the required 1.5E 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

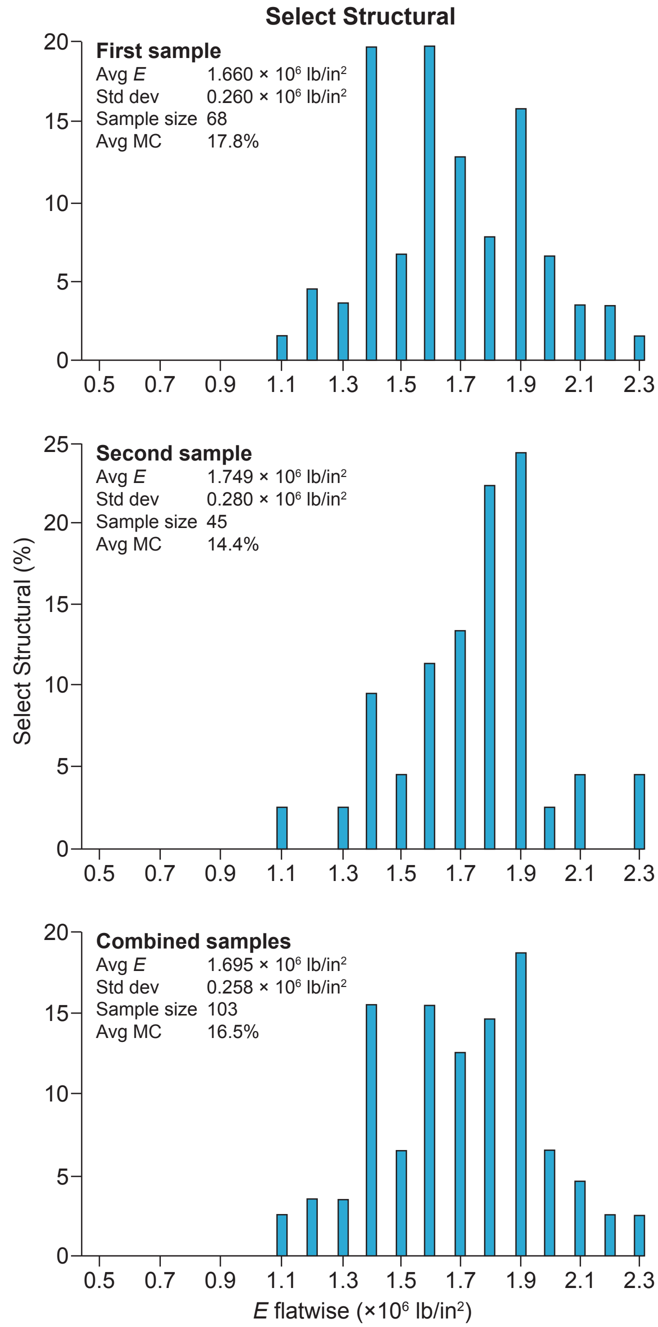

Figure 10—Flatwise *E* of 2 by 4 Select Structural lumber as measured by static tester. Results for two individual samples and combined samples.

E required for each grade of interest is only slightly greater than grade E in each case:

Grade	Average E from graph
1,650f–1.5E	1.52
2,100f–1.8E	1.82
2,400f–2.0E	2.01

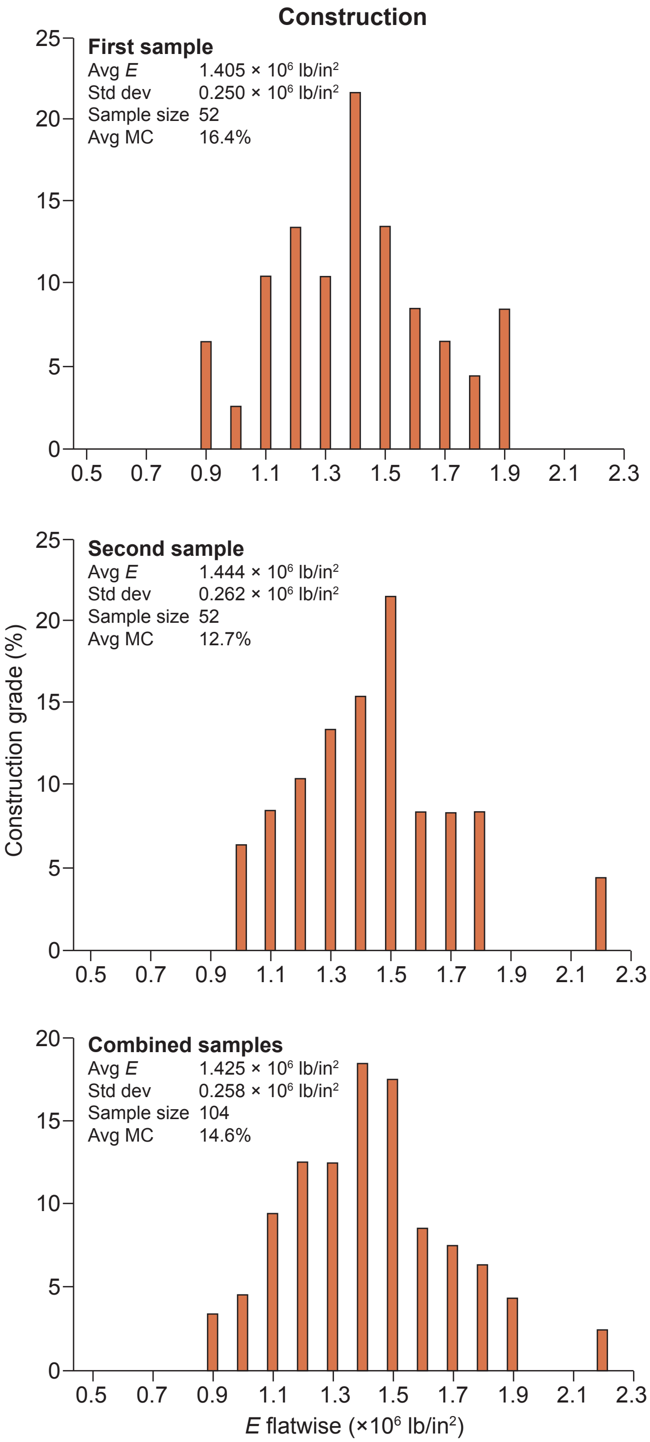

Figure 11—Flatwise *E* of 2 by 4 Construction grade lumber as measured by static tester. Results for two individual samples and combined samples.

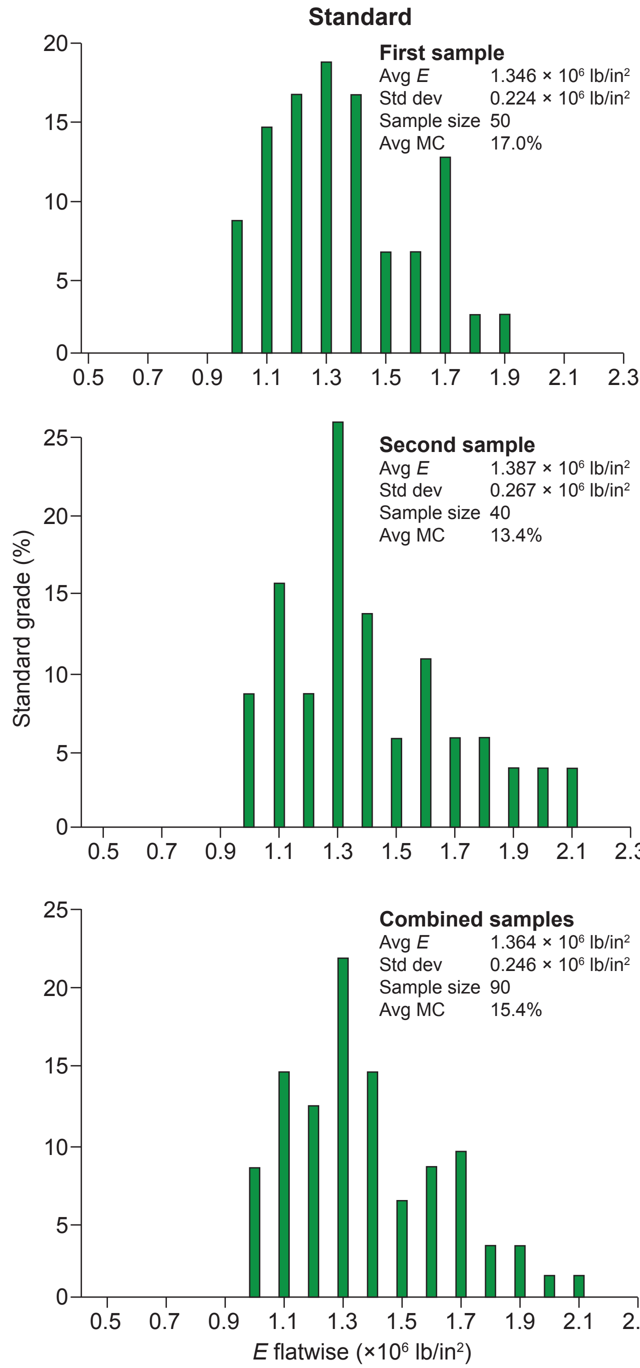

Figure 12—Flatwise *E* of 2 by 4 Standard grade lumber as measured by static tester. Results for two individual samples and combined samples.

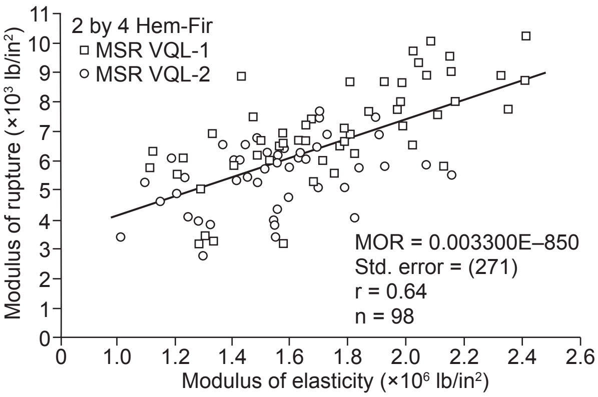

Figure 13—Relationship between modulus of rupture (MOR) and flatwise modulus of elasticity (MOE) as measured by static tester.

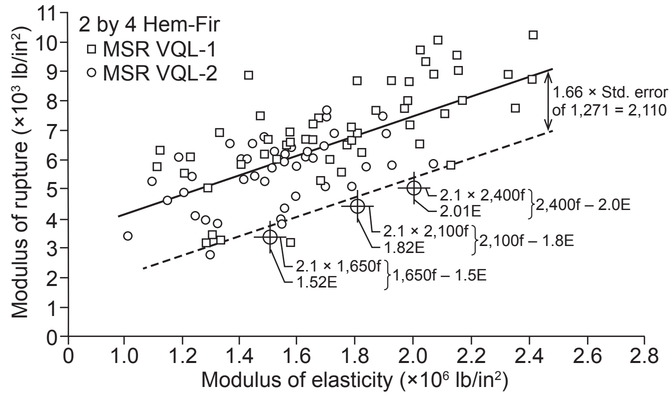

Figure 14—Estimate of average *E* required to maintain F_b of grade. Lower line is estimate of 5% exclusion limit for MOR for purpose of grade yield estimation process.

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.

Another way to obtain this estimate when using the entire WWPA procedure (WWPA 2017, 2008) is to select a minimum average *E* for a grade as 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 graphical manner from *E* distribution histograms (Figs. 10–12, 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 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 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% (six 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 2,400f–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 2,100f–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

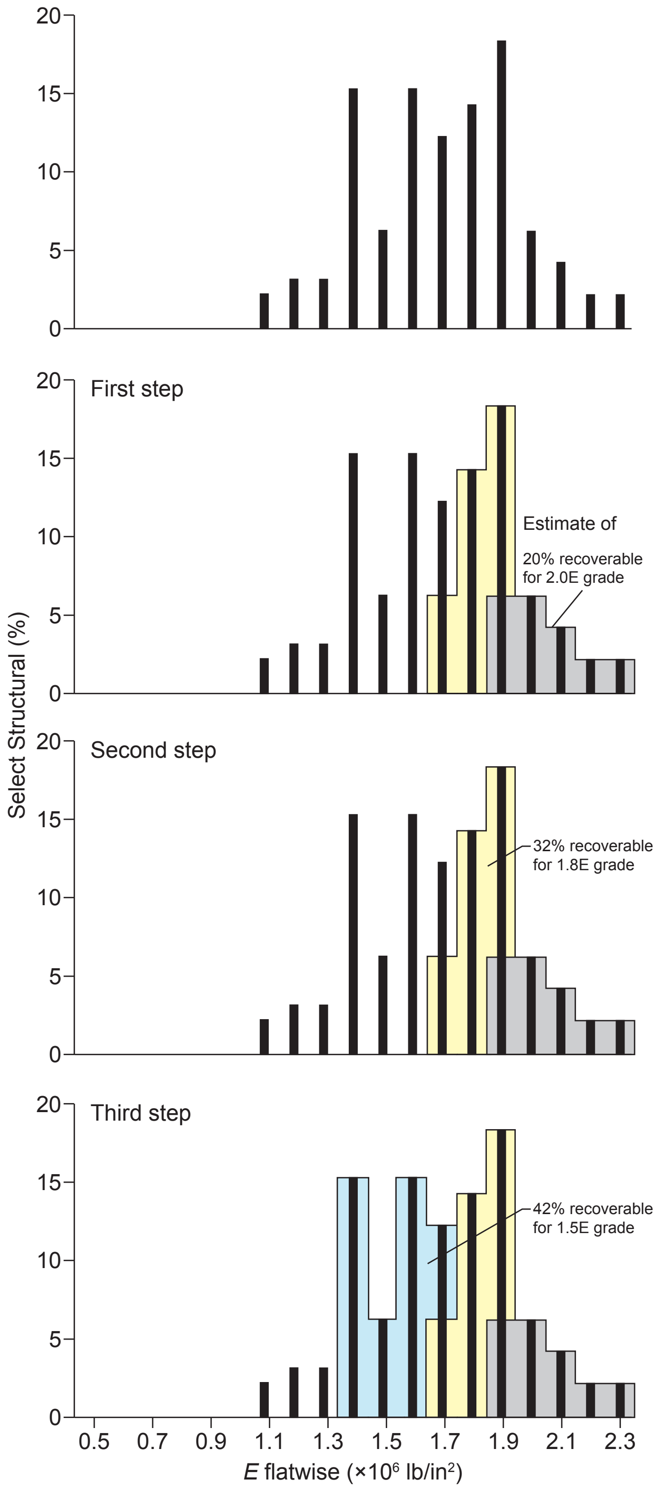

Figure 15—Procedure for estimating fraction of Select Structural 2 by 4's recoverable by *E* measurement. Data from Figure 10, combined results.

Thus, the estimate is that 32% of Select Structural 2 by 4's is qualified by the machine grading process for inclusion in the 2,100f–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 1,650f–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 1.5E. If the 6% remaining in the 1.7E class (six 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 is qualified by the machine grading process for inclusion in the 1,650f–1.5E grade.

This procedure for estimating should also be applied to the *E* distribution histograms developed for Construction and Standard grades, as shown in Figures 16 and 17. If this rather arbitrary treatment of data increases concern about the reliability of the 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 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 resources.

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 15.

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

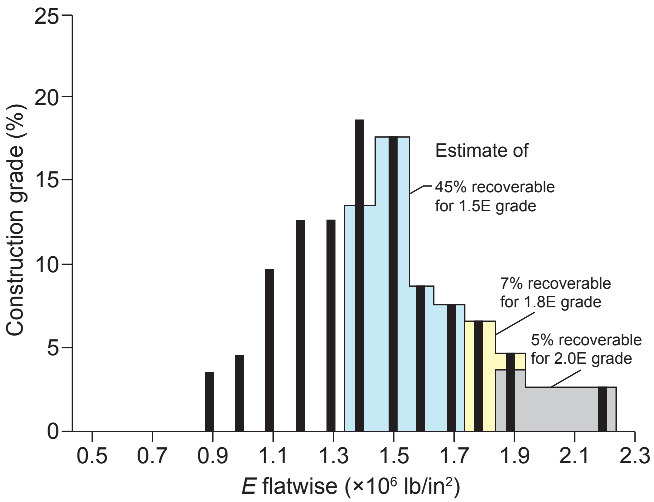

Figure 16—Estimate of fraction of Construction grade 2 by 4's recoverable by *E* measurement. Data from Figure 11, combined data, using procedures shown in Figure 15.

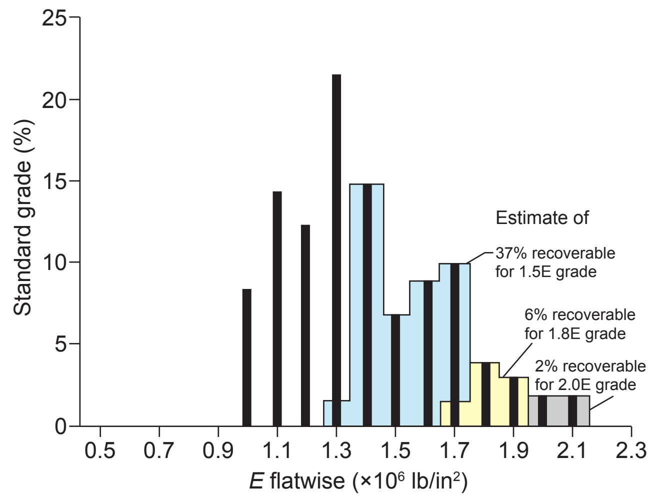

Figure 17—Estimate of fraction of Standard grade 2 by 4's recoverable by *E* measurement. Data from Figure 12, combined data, using procedures shown in Figure 15.

Table 15—Estimate of recoverable fraction of machine grades from visual grades

Visual grade	Machine grade	Fraction qualified for machine grade: Machine *E*	Fraction qualified for machine grade: Grader VQL–1	Fraction qualified for machine grade: Grader VQL–2	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		
	2100f–1.8E	0.07	0.22		
	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.

machine stress grade that can be made of VQL–2 is 1,650f–1.5E. Therefore, based on the *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 1,650f–1.5E recoverable is this number multiplied by the fraction of VQL–2 contained in the visual grade in question (Table 15). Actually, the VQL and *E* yields are not independent; therefore, experience has shown that the abovementioned assumptions are suitable for a feasibility analysis.

Table 16 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 15). The rounded percentages from the resultant fractions are 2,400f–2.0E, 2%; 2,100f–1.8E, 3%; and 1,650–1.5E, 19%.

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

Table 16—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
			2400/2.0	0.19	11,500		
Select Structural	6	60,000	2100/1.8	0.31		18,600	
			1650/1.5	0.44			26,400
			2400/2.0	0.01	5,500		
Construction	55	550,000	2100/1.8	0.02		11,000	
			1650/1.5	0.26			143,000
			2400/2.0	—			
Standard	22	220,000	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 17—Estimated proportions of 2 by 4 product mix under current and proposed visual plus machine product mixes[a]

Grade	Current product mix Fraction	Current product mix Board feet/ 10^6 board feet	Proposed product mix Fraction	Proposed product mix 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.

always exposes other alternatives for consideration. For this example, the proposed mix of visual and machine grades is contrasted with the current product mix in Table 17. 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 17 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 ensure 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 from that achieved with a "laboratory-type" sorting device because production measuring errors (contributions) will be incorporated in the data.

Machine Visual Grading

The analysis of machine visual grading may be simpler than the analysis of machine stress grading. Typically, a mill will select a random sample of lumber and have the mill certified grader carefully grade the lumber and determine the maximum value that the sample would be worth in the market place. The lumber is then evaluated by the prospective machine (there are five or six companies marketing visual grading machines in the United States) (App. B) and the product mix and value of the lumber are determined. A simple comparison is made by the mill to ensure that the machine accurately grades lumber to visual grading standards.

The above analysis ignores one very important aspect of the analysis for machine visual grading. Many machine grading systems can accept input from visual grading personnel. Machine stress grading machines employing stress wave analysis can send a stress grade to the visual grading machine and it will evaluate the options for each board to achieve maximum value. An analysis with focus on visual grade comparison only ignores the value of computer optimization that includes combinations of visual and machine stress grades.

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 E includes an example of one type of grade matrix analysis.

Mill Application

Considering 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?

Varieties of machines are available for machine grading of lumber. Most 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. Appendix B provides detailed information on machines that use bending, transverse vibration, longitudinal stress wave (acoustic), or density technologies.

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 reasonably accurate results. Throughput for these machines can be measured in pieces per minute and board footage per minute, rather than linear feet per minute, 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 (NIST 2020) 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 stress grading contact an ALS-certified grading agency for current information. The criterion for approval is that the machine demonstrates the ability to segregate lumber in accordance with the measurement system employed, such as stiffness or density measurement. The evidence provided shall include determination of measurement accuracy, including appropriate statistical analysis and is relative to an accepted consensus standard. Information listing the manufacturer's recommended operational limits is required, including information on machine measurement repeatability, variability, and recommended limits for the machine environment, such as temperature, operational speed, and humidity, as well as lumber conditions such as temperature, moisture content, and warp.

Detailed specifications for machine approval, agency accreditation, qualification procedures for a mill or facility by an agency, agency requirements for mill quality control, residual production, and ALSC monitoring of agencies are provided in the ALSC machine-graded lumber policy (App. A; ALSC 2020). Although not included in this handbook, ALSC Board of Review identifies operation limitations for this equipment. Current information and limitations can be accessed at the ALSC webpage (http://www.alsc.org/).

If the grades to be produced are E-rated for the glued-laminated beam industry, the provisions of ANSI A190.1 and reference documents must be met (APA 2017, 2015, 2013a,b). Agencies supervising E-rating must be qualified under ANSI or ALS. Machines used for stress grading lumber are also candidates for grading E-rated laminated lumber. Criteria for grading, for quality control, and for approval are different from 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.

Recently, significant numbers of longitudinal stress wave (acoustic) machine grading equipment have been installed. This equipment is installed so that the end of each piece of lumber is impacted and the lumber assessed as it travels transversely along a conveyor line after passing through the planning operation.

The variety of machines available today offers choice in mode of operation and environmental requirements. Some devices are heavier than others; therefore, 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, while 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 type of machine technology and 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 is 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 be 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.

Due to production speed improvements in bending machines and the introduction of acoustic systems, few off-line installations are used. However, those systems that are 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 F (Figs. 18–25) 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 can be used that is similar to those shown in Figures 18 to 24 in Appendix F. 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 (App. F).

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. F, Fig. 25). This type of 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 shown in Figure 25B.

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

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 consistent and controlled moisture content. Proper sticker placement not only affects efficient drying, but also minimizes warp that can influence the grading machine. Insufficiently dried lumber will likely be mis-graded 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 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 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 to 30 °F during the operating period.

Keeping spare parts on hand will significantly minimize lost production time. Fortunately, 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 and Topics

Mill Flow

As Figures 18 to 25 (App. F) 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 laminated 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.

Furthermore, recent introductions of longitudinal stress wave (acoustic) machines have resulted in lumber being graded as it travels transversely on a lumber conveyor line. This has helped reduce the footprint required for linear travel of the lumber through the grader and in-line deflection-based equipment. For an example, see Figure 18. For optimizing longitudinal stress wave (acoustic)/thumper machines in your operation, work with a local dealer and supplier. For additional information on installation layouts, equipment suppliers are able to provide more detailed recommendations on current installation options for each mill layout.

Processing Interactions

The actual machine grading operation is one of the final processing steps in a mill. As a result, lumber that reaches the grading machine is the result of all previous processing steps. Because machine grading measures some physical or mechanical properties and incorporates visually detected characteristics, the process is more sensitive to some processing steps than is visual grading. As noted previously, these include the effect of drying on stiffness measurement and the quality of surfacing on machine response. However, this sensitivity to processing extends well "upstream" to initial log selection, log breakdown, and all subsequent operations that affect the variable or variables measured by the machine system.

Log Selection and Primary Breakdown

The influence of log selection and initial breakdown is based on wood quality. This, in turn, is affected by the age of the tree and by the location of the log in the stem, as well as other variables. A number of log features can produce less desirable lumber. Machine grading will sense these features—a desirable result from a grading perspective. However, negative effects on grade yield may be countered somewhat by such practices as the proper selection of the log and the method of log bucking.

All trees contain juvenile wood and the proportion of this wood varies by the age of the wood and by log location in the stem. Juvenile wood is lower in stiffness and strength than is mature wood and directly affects the yield of machine grades. Butt logs often contain severe swell, which results in growth ring and fiber distortion in the lumber cut from this region. Severe taper and sweep can result in lumber with severe slope of grain, which is detected by some grading systems. Logs from leaning trees may contain compression wood (in softwood species) or tension wood (in hardwood species) and both are termed abnormal wood and will reduce lumber yield of higher machine grades. The incidence of abnormal wood and its characteristics varies with species. In summary, the most fundamental wood characteristics observed in machine grade yield studies originate in and are controlled in large measure by tree and log selection.

Sawmill Processing

When the tree-length log is bucked into processing log lengths, the lumber quality scenario narrows in focus. Log length decisions interact with market desires for lumber length. Market desires for length vary by grade; for example, longer lengths for higher grades (longer span end uses) and shorter lengths for lower grades (wall and floor elements). However, grade may also influence the decision—long length wood consisting of juvenile wood will not make a high grade. This is further confounded by the radial gradient of quality of the stem, generally low to high, pith to bark. Because the geometry of cutting rectangles from circles dictates that wide widths must be cut close to the pith, the grade influence of radial wood quality gradients interacts with lumber width. These variables all affect yield of machine grading systems that are sensitive to wood quality in the stem. This, in turn, affects market targets for the mill.

Mill edging and trimming operations are critical to any lumber grading system. They are particularly important to machine grading because grading machines will respond adversely to physical or mechanical characteristics in the lumber, such as slope of grain, that may have been avoided with better processing. Conversely, the machine system can respond positively to good wood such as higher density/higher stiffness wood next to acceptable wane from the outer part of the stem. If the machine grade target is E-rated laminated (lam) stock, edging for lam stock takes special attention and can be linked to discernable wood quality features. Good edging practices are rewarded. It should also be noted that machines configured to capture stiffness or density measurements along the length of the board have the potential to optimize value by length and grade.

Drying and Planing

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 excessively dried. 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 over-drying.

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, then 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; therefore, insufficient cooling time will result in reduced yield.

Lumber size and surface quality interact with drying practices as well as many "upstream" mill-processing procedures. Surfacing quality is important to any system that must contact the lumber—as in stiffness-based machines that employ rolls and contact sensors. Holding tight planing tolerances is feasible with modern planers; this enhances yield when coupled with good mill sizing and dry kiln practices. However, sizing tolerances are strict for machine-graded lumber destined for laminating. Good planing opens this market potential.

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 and anticipated production rate and up-time for out-of-line operation
- Special concerns
  - Available space
  - Proximity to planer or in line with planer
  - Proximity to ancillary equipment
  - Mill environment (temperature, humidity, vibration, electronic noise)
  - Maintenance and quality assurance (Experience has shown that grading machine maintenance often requires a staff who understands 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.)

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 checklist of concerns that should be reviewed.

1. Flow (continuous or stop & go)—Some machines take multiple measurements as the piece passes through the machine, whereas 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, whereas others require pieces to be turned on edge.
4. In-feed 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

The MSR and MEL are the two types of machine-graded lumber produced in North America under the auspices of the American Lumber Standard Committee (ALSC) (Galligan and McDonald 2000). The ALS maintains the American Softwood Lumber Standard (Voluntary Product Standard PS 20 (NIST 2020), published by the National Institute for Standards and Technology) and in accordance with PS 20 administers an accreditation program for the grademarking of lumber produced under that system. With regard to machine-graded lumber, the *Machine Graded Lumber Policy* of the ALSC sets forth the procedures for grademarking of machine-graded lumber conforming to the American Softwood Lumber Standard PS 20. The policy also includes requirements specific to the machine-graded lumber process and to the approval of the machines (App. B; ALSC 2020). (The current lumber policy and list of machines is available at http://www.alsc.org/untreated_machinegraded_mod.htm). Further, machines used to develop machine grades in North America as of 2020, under ASLS PS–20 or ANSI A190.1, are listed in Appendix B.

Literature Cited

AF&PA/AWC. 1997. National design specification for wood construction, 1997 edition. Washington, DC: American Forest and Paper Association and American Wood Council. https://awc.org/codes-standards/publications/nds-1991-1997 and https://awc.org/pdf/codes-standards/publications/nds/archives/AWC-NDS1997-Commentary.pdf. (See latest edition.)

ALSC. 2020. American Lumber Standard Committee, Incorporated, general info, summary. Germantown, MD: American Lumber Standard Committee http://www.alsc.org/geninfo_summary_mod.htm.

APA. 2013a. American national standard for wood products—structural glued laminated timber. ANSI A190.1–2012 (previously ANSI/AITC A190.1). Tacoma, WA: APA–The Engineered Wood Association. https://www.apawood.org/Data/Sites/1/documents/standards/a190-1/a190.1-2012.pdf. (See latest edition.)

APA. 2013b. Standard specifications for structural glued laminated timber of softwood species. ANSI 117-2010/AITC 117: 2010. Tacoma, WA: APA–The Engineered Wood Association. https://www.anthonyforest.com/assets/pdf/apa/glulam/ANSI-117_2010.pdf. (See latest edition.)

APA. 2015. Standard specifications for structural glued laminated timber of softwood species. ANSI 117-2015/AITC 117: 2015. Tacoma, WA: APA–The Engineered Wood Association. https://www.americanlaminators.com/tech/ANSI+117-2015.pdf. (See latest edition.)

APA. 2017. American national standard for wood products—structural glued laminated timber. ANSI A190.1–2017 (previously ANSI/AITC A190.1). Tacoma, WA: APA–The Engineered Wood Association. https://www.apawood.org/ansi-a190-1. (See latest edition.)

ASTM. 2019. Annual book of ASTM standards, Volume 04.10 Wood. West Conshohocken, PA: American Society for Testing and Materials. https://www.astm.org/. (See latest edition; July 2019 version at time of printing.)

ASTM D1990-19 Standard practice for establishing allowable properties for visually-graded dimension lumber from in-grade tests of full-size specimens

ASTM D3737-18e1 Standard practice for establishing allowable properties for structural glued laminated timber (glulam)

ASTM D4761-19 Standard test methods for mechanical properties of lumber and wood-base structural material

ASTM D6874-12 Standard test methods for nondestructive evaluation of wood-based flexural members using transverse vibration

AWC. 2012. National design specification (NDS) for wood construction and NDS supplement: design values for wood construction, 2012 edition. Leesburg, VA: American Wood Council. https://awc.org/codes-standards/publications/nds-2012 and https://awc.org/pdf/codes-standards/publications/nds/AWC-NDS2012-ViewOnly-1506.pdf. (See latest edition.)

AWC. 2015. National design specification (NDS) for wood construction and NDS supplement: design values for wood construction, 2015 edition. Leesburg, VA: American Wood Council. https://awc.org/codes-standards/publications/nds-2015 and https://awc.org/pdf/codes-standards/publications/nds/AWC-NDS2015-ViewOnly-1603.pdf. (See latest edition.)

AWC. 2018. National design specification (NDS) for wood construction and NDS supplement: design values for wood construction, 2018 edition. Leesburg, VA: American Wood Council. https://awc.org/codes-standards/publications/nds-2018 and https://awc.org/pdf/codes-standards/publications/nds/AWC-NDS2018-ViewOnly-171117.pdf. (See latest edition.)

Brown, L.S.; DeVisser, D.A.; Tuvey, R.S.; Rozek, A. 1997. Mechanically graded lumber: the grading agency perspective. Wood Design Focus. 8(2): 3–7.

Forest Products Laboratory. 2010. Wood handbook: wood as an engineering material. General Technical Report FPL–GTR–190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 509 pp. https://www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr190.pdf

Galligan, W.L. 1985. Reflections on model-based QC for MSR lumber. In: Proceedings of 5th nondestructive testing of wood symposium. Pullman, WA: Washington State University: 613–644.

Galligan, W.L.; Courteau, R.W. 1965. Measurement of elasticity of lumber with longitudinal stress waves and the piezoelectric effect in wood. In: Galligan, W.L. (ed.), Proceedings of the 2nd nondestructive testing of wood symposium. Pullman, WA: Washington State University: 223–244.

Galligan, W.L.; DeVisser, D.A. 1998. Evaluating the ratio of allowable tensile strength to allowable bending strength for MSR grades. Presented at the Annual Meeting of Forest Products Society, June 1998, Merida, Yucatan, Mexico.

Galligan, W.L.; McDonald, K.A. 2000. Machine grading of lumber—practical concerns for lumber producers. General Technical Report FPL–GTR–7 (Revised). Madison, WI: U.S. Department of Agriculture, Forest Services, Forest Products Laboratory. 39 pp. https://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr07.pdf.

Galligan, W.L.; Moyer, L. 1968. A status report: nondestructive testing of lumber. In: Proceedings, Symposium “Focus 70.” Vancouver, BC, Canada: Council of Forest Industries.

Galligan, W.L.; Snodgrass, D.V. 1970. Machine stress-rated lumber: challenge to design. In: Proceedings, American Society of Civil Engineering. Journal of Structural Division. (ST12) 96: (Pap. 7772): 2639–2651.

Galligan, W.L.; Snodgrass, D.V.; Crow, G.W. 1977. Machine stress rating—practical concerns for lumber producers. General Technical Report FPL–GTR–7. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 88 pp. https://apps.dtic.mil/dtic/tr/fulltext/u2/a038926.pdf

Galligan, W.L.; Gerhards, C.C.; Ethington, R.L. 1979. Evolution of tensile design stresses for lumber. General Technical Report FPL–GTR–28. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 12 pp. https://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr28.pdf

Galligan, W.L.; Hoyle, R.J., Jr.; Pellerin, R.F.; Haskell, J.H.; Taylor, J.R. 1986. Characterizing the properties of 2-inch softwood dimension lumber with regressions and probability distributions: Project Completion Report. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 135 pp.

Galligan, W.L.; Shelley, B E.; Pellerin, R.F. 1993. The influence of testing and size variables on the tensile strength of machine stress-rated lumber. Forest Products Journal. 43(4): 70–74.

Hoyle, R.J., Jr. 1970. Estimating profits from MSR grading. In: Proceedings, Third Short Course, Machine Stress-Rated Lumber. Pullman, WA: Washington State University.

Huang, C.L. 2011. Chapter 11: Industry prospective of delamination in wood and wood products. In: Bucur, V. (ed.), Delamination in wood, wood products and wood-based composites. Heidelberg, Germany: Springer Netherlands: 215–236.

Kline, D.E.; Conners, R.W.; Araman, P.A. 1998. What's ahead in automated lumber grading. Scan Pro Conference—8th International conference on scanning technology and process optimization for the wood products industry. San Francisco, CA: Miller Freeman, Inc. 13 pp. http://www.srs.fs.usda.gov/pubs/VT_Publications/9834.pdf

Kretschmann, D.E. 2010. Stress grades and design properties for lumber, round timber, and ties. In: Wood handbook: wood as an engineering material. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 7-1–7-16. 15pp.

Logan, J.D.; Kreager, P.S. 1975. Using a microprocessor: a real-life application. part 1—hardware. Computer Design. 14(9): 69–77.

McKean, H.B.; Hoyle R.J. 1964. Stress-grading method for dimension lumber. Special Technical Publication No. 353. West Conshohocken, PA: American Society for Testing and Materials.

MSR Lumber Producers Council. 1996. 1996 MSR lumber production survey. Helena, MT: MSR Lumber Producers Council.

MSR Lumber Producers Council. 2019. MSR Lumber Producers Council (website). Helena, MT: MSR Lumber Producers Council. http://www.msrlumber.org/

NIST. 2020. American softwood lumber standard voluntary product standard PS 20–20 (ALS). Gaithersburg, MD: U.S. Department of Commerce, National Institute for Standards and Technology. https://www.nist.gov/system/files/documents/2019/12/11/PS%2020-20%20final%20WERB%20approved.pdf. (See latest edition.)

Ross, R.J. 2015. Nondestructive evaluation of wood, second edition. General Technical Report FPL–GTR–238. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 176 pp. https://www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr238.pdf

Ross, R.J.; Wang X. 2012. Nondestructive testing and evaluation of wood—50 years of research: International Nondestructive Testing and Evaluation of Wood Symposium series. General Technical Report FPL–GTR–213. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 6,702 pp. https://www.fs.usda.gov/treesearch/pubs/41649

Schajer, G.S. 2001. Lumber strength grading using x-ray scanning. Forest Products Journal. 51(1): 43–50.

Senft, J.F.; Suddarth, S.K.; Angleton H.D. 1962. A New approach to stress grading of lumber. Forest Products Journal. 12(4): 183–186.

SPIB. 2014. Standard grading rules for southern pine lumber, 2014 edition. Pensacola, FL: Southern Pine Inspection Bureau. https://www.spib.org/about-us/publications. (See latest edition.)

WCLIB. 2020. WCLIB history. Tigard, OR: West Coast Lumber Inspection Bureau. https://www.wclib.org/about/

WWPA. 1976. Special product rules. Portland, OR: Western Wood Products Association. https://www.wwpa.org/. (See latest edition.)

WWPA. 2008. Western lumber product use manual. Portland, OR: Western Wood Products Association. 24 pp. https://www.twincreeksloghomes.com/images/Pdf/wwpa-product-use-manual-sm.pdf. (See latest edition.)

WWPA. 2011. Western lumber grading rules 2011. Portland, OR: Western Wood Products Association. 252 pp. http://www.wwpa.org/. (See latest edition.)

WWPA. 2017. Western lumber grading rules 2017. Portland, OR: Western Wood Products Association. 252 pp. https://www.wwpa.org/resources/?topics=e4ae6d8f-ad3b-6952-b602-ff00000b7aec. (See latest edition.)

Ziegler, G. 1997. Machine grading processes for softwood lumber. Wood Design Focus. 8(2): 7–14.

Appendix A—American Lumber Standard Committee, Machine Graded Lumber Policy

Following is an outline list of the American Lumber Standard Committee, Machine Graded Lumber Policy as of November 15, 2019. This policy has been authorized by the Board of Review and goes through the machine approval, agency accreditation, qualification procedures of a mill, agency requirements for a mill quality control, residual production and ALSC monitoring of agencies. http://www.alsc.org/greenbook collection/UntreatedProgram_MachineGradedPolicy.pdf

AMERICAN LUMBER STANDARD COMMITTEE, INCORPORATED®

MACHINE GRADED LUMBER POLICY
November 15, 2019

A) General

1) The Board of Review is authorized to determine the competency, reliability and adequacy of agencies that apply for accreditation as an agency to supervise machine grading of lumber products.
2) The Board is also authorized to monitor the proficiency of accredited agency's supervision of the machine grading of lumber products where such products are grade stamped as conforming to the American Lumber Standard.
3) In its monitoring of agency supervision of machine grading of lumber, the Board is authorized to utilize appropriate and recognized test procedures and criteria in determining that specific machines and methods of machine graded lumber products are in compliance with:
   a) approved grading rules;
   b) product standards; and
   c) grade stamp requirements
4) The Board is authorized to require an agency, which does not employ staff technicians, to utilize services of consultants satisfactory to the Board for verifying compliance to this policy.
5) The Board may employ consultants to review evidence and data submitted pertaining to this policy.
6) All consultants' expenses shall be borne by the applicant agency.

B) Machine Approval

The American Lumber Standard Committee (ALSC) has established the following criteria for approval of machines used for machine grading:

1) An applicant agency shall provide the Board with an explanation of the type of machine(s) for which approval is desired and shall include a general description of the theoretical and practical basis on which the machine(s) operate(s).
2) An applicant agency shall provide the Board with evidence that the machine(s) is capable of measuring the physical or mechanical property used by the machine for the classification or segregation of lumber. The evidence provided shall include determination of measurement accuracy, including appropriate statistical analysis and is relative to an accepted consensus standard. The report shall provide information listing the manufacturer's recommended operational limits including information on machine measurement repeatability, variability, and recommended limits for the machine environment such as temperature, operational speed, and humidity, as well as lumber conditions such as temperature, moisture content, warp, etc.

C) Agency Accreditation

The American Lumber Standard Committee has established the following criteria for accreditation of an agency to conduct an on-going quality control and grade-stamping program for machine graded lumber:

1) All agencies shall provide ALSC with certification and quality control procedures to be utilized in authorizing mills to grade stamp machine graded lumber.
2) Non-rules-writing agencies shall utilize qualification and in-plant quality control procedures that provide product performance at least equivalent to the requirements of rule-writing agencies.

Note: This may be demonstrated through a documented comparison of qualification and quality control procedures using standard statistical methodology and analysis.

3) Rules-writing and non-rules-writing agencies shall conduct a minimum of 12 inspections per year, at approximately monthly intervals, of the visual grading accuracy of grade stamped machine graded lumber at each mill or facility under its supervision. When a mill or facility is inactive for at least one month, an inspection shall be required for each month the mill or facility is actively producing machine graded lumber.
4) Rules-writing and non-rules-writing agencies shall review the mill or facility quality control records as part of the inspection. The agency inspection reports shall note any deficiencies found and corrective actions taken.
5) Rules-writing and non-rules-writing agencies shall require in-plant test records to be retained for at least one year.
6) Rules-writing and non-rules-writing agencies shall provide for re-grading of lumber when production lots are rejected because of the in-plant quality control process.
7) Rules-writing and non-rules-writing agencies shall require periodic, at least monthly, calibration of in-plant test equipment by mill or facility personnel, and third party calibration (NIST traceable) at least annually.

8) Grade marks on machine graded lumber shall be distinguishable from grade marks of visually graded lumber. Facsimiles of marks shall be on file with the Board of Review.
9) Rules-writing agencies shall provide re-inspection procedures for machine graded lumber.

D) Qualification Procedures of a Mill or Facility by the Agency

1) Prior to qualification of a machine grade, the agency shall verify that:
   a) The mill or facility is using an ALSC approved grading machine; and
   b) The in-plant grading process (combined machine and visual) is capable of producing lumber grades that meet all of the requirements stipulated in the applicable grade rules, product standards or equivalent procedures.
2) Agency qualification of a machine grade(s) shall verify that the qualification sample for the grade being qualified meets the following minimum criteria:
   a) Visual: All pieces in the qualification sample meet the visual requirements of the applicable grading rule.
   b) For MSR:
      i) Average edge modulus of elasticity (MOE) equal to or greater than the assigned average E;
      ii) 95% of pieces have edge MOE greater than 82% of assigned average E;
      iii) 95% of pieces have a modulus of rupture (MOR) greater than 2.1 times the assigned F_b.
   c) For MEL:
      i) Average edge MOE equal to or greater than the assigned average E;
      ii) 95% of pieces have an edge MOE greater than 75% of assigned average E;
      iii) 95% of pieces have a MOR greater than 2.1 times the assigned F_b;
      iv) 95% of pieces have an ultimate tensile strength (UTS) greater than 2.1 times the assigned F_t.

E) Agency Requirements for Mill Quality Control

The agency shall require that mills or facilities that grade machine graded lumber conduct daily quality control of the machine graded output. As a minimum, the quality control procedures shall include the following components:

1) Offline measurement of MOE;
2) Offline strength testing to verify assigned F_b and/or F_t. Testing may be conducted by proof testing using appropriate proof loading equipment. Proof loading equipment is defined as equipment capable of imposing a stress on the test specimen of at least 2.1 times the assigned property value.

Note: This requirement may be waived for MSR mills manufacturing lumber from a clearly identified uniform timber resource (from a definable and sampled timber source).

3) Verification of daily test results to the quality control requirements established by the agency.
4) Procedures for regrading of lumber identified by the quality control procedures as non-conforming with the grade specifications.
5) All agencies shall conduct periodic physical tests of at least one grade, one size and one species to check lumber output criteria specified in section D) 2). Semi-annual tests are deemed adequate where CUSUM quality control is used. For machine stress rated lumber, lumber is tested for both MOE and MOR on edge or MOE and UTS. For mechanically evaluated lumber, lumber is tested for MOE and MOR as well as UTS.

F) Residual Production

1) Residual lumber is lumber which has passed through the machine grading process and was rejected from the minimum selection criteria for the lowest machine grade being produced.
2) Residual lumber may be placed in the highest visual grade for which it qualifies, provided that the design values assigned to the visual grade meets the following condition:
   a) MSR and MEL residual – Fiber stress in bending (F_b) of visual grade is lower than F_b assigned to the machine grade from which the piece was rejected.
3) Residual lumber products shall be grade stamped at the production site in accordance with existing ALS provisions or, if shipped not grade stamped, marked in a fashion to indicate the lumber has been passed through machine grading equipment.

G) ALSC Monitoring of Agencies

The American Lumber Standard Committee has established the following policies for the Board in carrying out its responsibility to monitor agencies for the supervision of the machine grading of lumber:

1) ALSC may inspect grade stamped machine graded lumber to determine if it meets visual grade requirements.
2) ALSC may review mill or facility records to determine if producers are maintaining records required by their agencies.
3) ALSC may review agency records to determine if monthly inspections are being performed.
4) ALSC may require physical tests to be performed on already grade stamped machine graded lumber production if there is reason to believe an agency's on-going procedures are not resulting in conformance of lumber output to the criteria specified in grade certification. ANSI/ASQC Z1.4 Standard may be used as a guide for sampling procedures.

Appendix B—List of Trade Names of Commercial Grading Equipment Machines Approved by the Board of Review

As of January 2020 (http://www.alsc.org/greenbook%20collection/grading_machines.pdf), following is a list of grading machines that have been approved by the Board of Review (BOR). For each of the 34 different grading machines, agency support, machine manufacturer, and BOR action are provided within the list.

Grading machines approved by the Board of Review

Grading machine	Agency support	Machine manufacturer	Board of Review (BOR) action
1. Metriguard Model 3300 Transverse Vibration E-Computer Metriguard Model 340 Transverse Vibration E Computer	WCLIB	Metriguard, Inc. PO Box 399 Pullman, WA 99163	Granted Model 3300 approval on 7/12/1984 for • Dry lumber only
2. Stress-O-Matic	WWPA	Industrial Woodworking Machines PO Box 1465 Garland, TX	Granted approval around 1962
3. C-L-T (Continuous Lumber Tester) C-L-T Model 7200 HCLT (High Capacity Lumber Tester)	WWPA for C-L-T	Metriguard Inc. PO Box 399 Pullman, WA 99163	Granted approval around 1962 for C-L-T
4. Cook Bolinder Model SG-TF NA	WWPA	Cook Bolinder Ltd. PO Box 42 Stansmore, Middlesex, GB HA7 4XD	Granted approval 1/23/1986
5. X-Ray Lumber Gauge [previously known as Advanced Stress Grader (BOR 10/26/89) no longer available]	SPIB	Newnes Machine Ltd. Company	Granted approval 4/1995 subject to • The use of visual slope of grain requirements for the various grade levels as found in ASTM D245 unless the X-Ray Lumber Gauge is used in conjunction with another method to evaluate slope of grain. • The moisture content of the stock being controlled and taken into account for the design value assignments. • The use of accredited agency quality control and certification procedures. If short runs are made, intensive sampling will be done through the accredited agency quality control program.
6. Dart M. S. R. Testing Machine	CMSA	Eldeco Pty Ltd. Albury, Australia	Granted approval 2/2/1995
7. Ersson ESG 240-Strength Grader	WCLIB	John Ersson Engineering AB Storvik, Sweden	Granted approval 2/5/1998
8. Dynagrade Strength Grading Machine	QLMA	Dynalyse AB Partille, Sweden	Granted approval 7/27/2000
9. Computermatic	WCLIB	Measuring and Process Control Ltd. Essex, UK	Granted approval 2/8/2001
10. Dimter 403 Grademaster	WCLIB	Dimter GmbH Maschineenfabric Illertissen, Germany	Granted approval 4/24/2003 with the following operational limitations of the machine: • Recommended range of the lumber temperature is 15–30 °C (59–86 °F). • Machine operation speed range is 25 pieces/min. • Lumber thickness range is 33–60 mm (1.30–2.36 in.). • Lumber width range is 80–220 mm (3.1–8.66 in.). • Lumber length range is 3,000–6,000 mm (118–236 in.). • Lumber surface must be planed. • Moisture content of lumber between 8% and 15%.

Grading machines approved by the Board of Review—con.

Grading machine	Agency support	Machine manufacturer	Board of Review (BOR) action
11. Microtec GoldenEye Lumber Grading Machine	WCLIB	MiCROTEC Srl GmbH Bressanone, Italy	Granted approval 4/24/2003 with the following operation limitations of the machine: • Recommended range of the lumber temperature is 15–30 °C (59–86 °F). • Recommended machine operating temperature is 0–45 °C (5–113 °F). • Machine operation speed range is 80–300 m/min (262–984 ft/min). • Lumber thickness range is 20–60 mm (0.79–2.36 in.). • Lumber width range is 80–300 mm (3.15–11.81 in.). • Moisture content of lumber between 8% and 15%.
12. Transverse MSR Grader (TMG)	QFIC	Centre de Recherche Industrielle du Quebec (CRIQ) Quebec, Canada	Granted approval 4/29/2004 with the following operation limitations of the machine: • Temperature—The equipment shall be operating at temperature above freezing point 32 °F (0 °C). • Humidity—The recommended environmental operating range for humidity is a maximum of 85% (no condensing). No lower limit. • Operational speed—The maximum operation speed is 160 pieces per minute. • Lumber thickness—The thickness range is from 0 to 2 in. Variance in thickness has no mechanical influence on the machine. • Lumber width—The lumber width range is from 3 to 4 in. • Lumber length—The minimum length of a piece of lumber that can be effectively graded is 6 ft. The maximum length is 9 ft. • Lumber temperature—The recommended lumber temperature operating range is –40 °F (–200 °C) as lower limit. No upper limit. • Number of grades—The capacity to segregate up to three different grade categories simultaneously.
13. Transverse MSR Grader (TMG) 12	QFIC	Centre de Recherche Industrielle du Quebec (CRIQ) Quebec, Canada	Granted approval 7/22/2004 with the following operation limitations of the machine: • Temperature—The equipment shall be operating at temperature above freezing point 32 °F (0 °C). • Humidity—The recommended environmental operating range for humidity is 85% (no condensing). No lower limit. • Operational speed—The maximum operation speed is 240 pieces per minute. • Lumber thickness—The thickness range is from 0 to 2 in. Variance in thickness has no mechanical influence on the machine. • Lumber width—The lumber width range is from 3 to 6 in. • Lumber length—The minimum length of a piece of lumber that can be effectively graded is 5 ft. The maximum length is 12 ft. • Lumber temperature—The recommended lumber temperature operating range is –4 °F (–20 °C) as lower limit. No upper limit. • Number of grades—The capacity to segregate up to three different grade categories simultaneously.

Grading machines approved by the Board of Review—con.

Grading machine	Agency support	Machine manufacturer	Board of Review (BOR) action
14. CRP 360 MSR Testing Machine	QFIC	Conception RP, St-Victor De Deauce Quebec, Canada	Granted approval 7/22/2004 with the following operation limitations of the machine: • Machine environmental conditions: –Ambient operating temperature—0 to 50 °C –Ambient humidity conditions—up to 90% humidity, no condensing. • Operational speed—The maximum operational speed is up to 800 ft/min. • Lumber thickness—The thickness range is up to 2 in. • Lumber width—The lumber width range is from 3 to 6 in. • Length capacity—The minimum length of a piece of lumber that can be effectively graded is 4 ft. • Lumber temperature—The recommended lumber temperature operating range is –20 °C and up. • Amount of grades identified—Four different grades simultaneously.
15. RE-II (formerly called XLG/LHG+Thumper Strength Grader)	SPIB	Weyerhaeuser	Granted approval February 3, 2005 with the following limitations of the machine: • The use of visual slope of grain requirements for the various grade levels as found in ASTM D-245 unless the XLG/LHG is used in conjunction with another method to evaluate slope of grain. • The moisture content of the stock being controlled and taken into account for the design value assignments. • The use of accredited agency quality control and certification procedures. If short runs are made, intensive sampling will be done through the accredited agency control program. • Lumber sizes –Thickness up to 4in. –Width up to 12 in. –Length up to 24 ft. • Pending future tests, lumber temperature must be above freezing, 32 °F (0 °C). • The maximum operational speed is 180 pieces per minute with the current computer configuration. Future speed improvements can be made.
16. Transverse MSR Grader (TMG) 16	QFIC	Centre de Recherche Industrielle du Quebec (CRIQ) Quebec, Canada	Granted approval 7/28/2005 with the following operation limitations of the machine: • Temperature—The equipment shall be operating at temperature above freezing point 32 °F (0 °C). • Humidity—The recommended environmental operating range for humidity is 85% (no condensing). No lower limit. • Operational speed—The maximum operation speed is 240 pieces per minute. • Lumber thickness—The thickness range is from 0 to 2 in. Variance in thickness has no mechanical influence on the machine. • Lumber width—The lumber width range is from 3 to 6 in. • Lumber length—The minimum length of a piece of lumber that can be effectively graded is 5 ft. The maximum length is 16 ft. • Lumber temperature—The recommended lumber temperature operating range is –4 °F (–20 °C) as lower limit. No upper limit. • Number of grades—The capacity to segregate up to three different grade categories simultaneously.

Grading machines approved by the Board of Review—con.

Grading machine	Agency support	Machine manufacturer	Board of Review (BOR) action
17. RE-I (formerly called Stand Alone Thumper Strength Grader)	SPIB	Weyerhaeuser	Granted approval 7/28/2005 with the following limitations of the machine: • The use of accredited agency quality control and certification procedures. If short runs are made, intensive sampling will be done through the accredited agency control program. • Lumber sizes –Thickness up to 4in. –Width up to 12 in. –Length up to 24 ft. • Pending future tests, lumber temperature must be above freezing, 32 °F (0 °C). • The maximum operational speed is 180 pieces per minute. • The machine shall only be used to evaluate dry lumber.
18. Falcon Engineering A-Grader	WCLIB	Falcon Engineering Inglewood, New Zealand	Granted approval 7/27/2006 with the following operation limitations of the machine: • Operating speed limitation of a maximum of 180 pieces per minute.
19. Microtec Goldeneye Model 706 Lumber Grading Machine	WCLIB	MiCROTEC Srl GmbH Bressanone, Italy	Granted approval 11/2/2006 with the following operation limitations of the machine: • Recommended range of the lumber temperature is above 32 °F (0 °C). • Recommended machine operating temperature is 5–35 °C (41–95 °F). • Machine operation speed range is 450 m/min (1,500 ft/min). • Maximum lumber thickness range is up to 150 mm (approximately 5.91 in.). • Maximum lumber width range is 500 mm (19.69 in.). • Moisture content of lumber between 8% and 19%.
20. Precigrader MSR Grading Machine	CLA	Dynalyse AB Partille, Sweden	Granted approval 2/8/2007 with operation limitations of the machine as stated in the CLA submission. Modified speed limitation from 180 lugs/min to 260 lugs/min (see SPIB submission 1/24/2019 meeting).
21. LHG:XLG With E-Valuator Stiffness Estimation with Vibration	WWPA	COE Newnes/McGehee	Granted approval 4/26/2007 with the following operation limitations of the machine: • Operational feed speed—800–2,500 ft/min. • Operational temperature— –30 to 50 °C. • Material sizes—2×3 to 2×12 • Metric thickness—33 to 55 mm • Metric width—70 to 300 mm • To eliminate planer noise that may affect the laser profile subsystem, the machine must not be close-coupled with the planer and board flow must be relatively smooth. Abrupt changes in feed speed and non-fluent board flow adversely affect frequency measurement and should be avoided.

Grading machines approved by the Board of Review—con.

Grading machine	Agency support	Machine manufacturer	Board of Review (BOR) action
22. RE-III (formerly called Thumper III)	SPIB	Weyerhaeuser	Granted approval 11/1/2007 with the following operation limitations of the machine: 1. Lumber sizes: • Thickness up to 4 in. • Width up to 12 in. • Length up to 24 ft 2. Temperature range: • Kiln dried lumber: –50 °to 50 °C. When dry lumber is processed while frozen, CUSUM samples must be warmed to between 10 and 30 °C before being bench tested. • Green lumber: 0 to 50 °C. 3. Maximum speed is 200 pieces per minute with a lug chain maximum speed of 350 ft/min. Higher rates could be obtained by putting in two Thumper units evaluating every other board. 4. The use of accredited agency quality control and product certification procedures.
23. MiCROTEC ViSCAN Lumber Grading Machine	WCLIB	MiCROTEC Srl GmbH Bressanone, Italy	Granted approval November 12, 2009 with the following operation limitations of the machine: • Operating temperature—The operating range of the temperature of the electronics is 5° C (41° F) to +35° C (95° F). • Lumber temperature—The range of lumber temperatures is ≥ –20° C (–4° F) with a mean moisture content of < 20%. • Operational speed—The maximum speed of measurement is 180 boards/minute. • Lumber thickness—The range of lumber thickness is from 0.70 in. (18 mm) to 7.25 in. (184 mm). • Lumber width—The range of lumber widths is from 2.25 in. (57 mm) to 12.50 in. (318 mm). • End of piece—Since the end of piece (approximately 18 in.) is evaluated by the ViSCAN, the “end of the piece” visual limitations in 206-b of WCLIB Standard Grading Rules No. 17 will not be applicable.
24. MiCROTEC ViSCAN-PLUS Lumber Grading Machine	WCLIB	MiCROTEC Srl GmbH Bressanone, Italy	Granted approval November 12, 2009 with the following operation limitations of the machine: • Operating temperature—The operating range of the temperature of the electronics is 5° C (41° F) to +35° C (95° F). • Lumber temperature: Lumber < 20% moisture content: The range of lumber temperatures is ≥ –20° C (–4° F). When lumber is processed at less than 0°C (32° F), samples collected as part of a quality control program must be warmed to > 0°C (32° F) prior to testing. Lumber > 20% moisture content: The range of lumber temperature is 0°C (32° F). • Operational speed—The maximum speed of measurement is 180 boards/minute. • Lumber thickness—The range of lumber thickness is from 0.70 in. (18 mm) to 7.25 in. (184 mm). • Lumber width—The range of lumber widths is from 2.25 in. (57 mm) to 12.50 in. (318 mm). • End of piece—Since the end of piece (approximately 18 in.) is evaluated by the ViSCAN- PLUS, the “end of the piece” visual limitations in 206-b of WCLIB Standard Grading Rules No. 17 will not be applicable.

Grading machines approved by the Board of Review—con.

Grading machine	Agency support	Machine manufacturer	Board of Review (BOR) action
25. Weyerhaeuser NR Company’s Gradescan®-Based Strength Grading System	SPIB	Weyerhaeser/Lucidyne Technologies GradeScan	Granted approval July 21, 2011 with the following operation limitations of the machine: • Lumber sizes: – Thickness up to 4 inches – Width up to 14 inches – Length up to 28 feet • Temperature range is –50° C to 50° C. When lumber is frozen, CUSUM samples must be warmed to between 10° C and 30° C before being bench tested. • The maximum speed at the thumper station is 200 pieces per minute with a lug chain maximum speed of 350 feet per minute. Higher rates could be obtained by putting in two Thumper units evaluating every other board. The automated visual grader (GradeScan®) scans lumber at planer speeds up to 3000 ft/min. • The use of accredited agency quality control and product certification procedures. • When used in combination with the RE-I or RE-III machine the manufacturer operational restrictions previously assigned to RE-I or RE-III machine are applicable depending on the selected configuration.
26. Ecoustic Board Grader	WCLIB	Calibre Equipment Limited Wellington, New Zealand	Granted approval 1/5/2012 with the following operation limitations of the machine: • Maximum operating speed—240 boards per minute. • Maximum width—14 in. • Maximum thickness—12 in. • Maximum length—28 ft. • Lumber temperature: –MC < 20%: –20 to 50 °C –MC ≥ 20%: 0 to 50 °C
27. Metriguard 2350 Sonic Grader	WCLIB	Metriguard, Inc. PO Box 399 Pullman, WA 99163	Granted approval 10/18/2012 with the following operation limitations of the machine: • Maximum operating speed—250 boards per minute. • Maximum thickness—12 in. • Maximum width—14 in. • Lumber temperature range: –MC < 20 %: –4 to 120 °F –MC ≥ 20% : 32 to 120 °F • Since the end of the piece (approximately 18 in.) is evaluated by the Metriguard 2350 Sonic Grader, the “end of the piece” visual limitations specified in paragraph 206 b of the WCLIB Standard Grading Rules No. 17 will not be applicable.
28. MTG	OLMA	Brookhuis Micro Electronics Enschede, Netherlands	Granted approval 4/17/2014 with the following operation limitations of the machine: • Not intended for timber treated by fire retardant products or modified timber. • Not intended for finger jointed lumber. • Lumber dimensions with internal Stress Wave Activator: –Length—1.6–26.2 ft (500–8,000 mm) –Width—2–10 in. (50–250 mm) –Thickness—0.6–4.5 in. (15–115 mm) • Lumber dimensions with external Stress Wave Activator: –Length—1.6–65 ft (500–20,000 mm) –Width—2–15 in. (50–400 mm) –Thickness 0.6–12 in. (15–300 mm) • Temperature range of equipment is 14 to 122 °F (–10 to 50 °C)

Grading machines approved by the Board of Review—con.

Grading machine	Agency support	Machine manufacturer	Board of Review (BOR) action
29. MTG BATCH	OLMA	Brookhuis Micro Electronics Enschede, Netherlands	Granted approval 4/17/2014 with the following operation limitations of the machine: • Not intended for timber treated by fire retardant products or modified timber. • Not intended for finger jointed lumber. • Lumber dimensions: –Length—1.6–26.2 ft (500–8,000 mm) –Width—2–10 in. (50–250 mm) –Thickness—0.6–4.5 in. (15–115 mm) • Temperature range of equipment is 14 to 122 °F (–10 to 50 °C).
30. MTG ESCAN	OLMA	Brookhuis Micro Electronics Enschede, Netherlands	Granted approval 4/17/2014 with the following operation limitations of the machine: • Not intended for timber treated by fire retardant products or modified timber. • Not intended for finger jointed lumber. • Lumber dimensions: –Length—1.6–26.2 ft (500–8,000 mm) –Width—2–10 in. (50–250 mm) –Thickness—0.6–4.5 in. (15–115 mm) • Temperature range of equipment is 14 to 122 °F (–10 to 50 °C).
31. VAB - MSR Lug Loader	QFIC	VAB Machines, Inc. Levis, Quebec, Canada	Granted approval on 4/26/2018 with the following operation limitations of the machine: • Not intended for timber treated by fire-retardant products or modified timber. • Not intended for finger jointed lumber. • Lumber dimensions: –Length—6–16 ft (152.4–406.4 mm) (modified 1/24/2019—see QFIC submission) –Width—2.5 in. (63.5 mm); 3.5 in. (88.9 mm); 5.5 in. (139.7 mm) –Thickness—1.5 in. (38.1 mm) • Maximum rate—200 boards/min (6–12 ft); 140 boards/min (14 and 16 ft) (modified 1/24/2019—see QFIC submission). • MOE span—1,000,000–3,000,000 lb/in^2. • Wood temperature range— –22 to 86 °F (–30 to 40 °C). • Wood moisture range—10% to 25%.
32. Microtec Goldeneye Model 806 Lumber Grading Machine	WCLIB	MiCROTEC Srl GmbH Bressanone, Italy	Granted approval 1/24/2019 with the following operation limitations of the machine: • Recommended range of the lumber temperature is above –4 °F (–20 °C). • Recommended machine operating temperature is 41–95 °F (approximately 5–35 °C). • Machine operation speed range is 240 boards/min or approximately 4,000 ft/min (1,219 m/min). • Maximum lumber thickness range is up to 103 mm (approximately 4 in.). • Maximum lumber width range is 305 mm (approximately 12 in.). • Mean moisture content of lumber less than 20%. • No “end of piece” limitations due to full-length scan.

Grading machines approved by the Board of Review—con.

Grading machine	Agency support	Machine manufacturer	Board of Review (BOR) action
33. Microtec Goldeneye Model 802 Lumber Grading Machine	WCLIB	MiCROTEC Srl GmbH Bressanone, Italy	Granted approval 1/24/2019 with the following operation limitations of the machine: • Recommended range of the lumber temperature is above –4 °F (–20 °C). • Recommended machine operating temperature is 41–95 °F (approximately 5–35 °C). • Machine operation speed range is 4,000 ft/min (1,219 m/min). • Maximum lumber thickness range is up to 103 mm (approximately 4 in.). • Maximum lumber width range is 305 mm (approximately 12 in.). • Mean moisture content of lumber less than 20%. • No “end of piece” limitations due to full length scan.
34. USNR Thor Acoustic MSR Grader	PLIB	USNR Woodland, WA, USA	Granted approval 1/9/2020 with the following operation limitations of the machine: • Operating environment 31–125 °F (0–52 °C). • Lumber temperature: –22 °F (–30 °C) if MC < 25%. • Lumber temperature: 32–125 °F (0–52 °C) if MC > 25%. • Max width: 14 in. (360 mm). • Max thickness: 16 in. (400 mm). • Max length: 33 ft (10 m). • Kiln-dried lumber MC < 25%. • Sawmill lumber (“Green”): No limit. • Machine operating up to 360 boards per minute.

Appendix C—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 (C-L-T) was called Electro-Mechanical Stress Rating (EMSR) 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 C-L-T 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 C-L-T was dropped, ALS accepted other machines, 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; therefore, 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” laminated machine grades, requires distinctive labeling linked to the different performance criteria.

Performance and Grademark Criteria

The ALS performance criteria for MSR, MEL, and E-rated lumber are shown in Table 18 and Table 19. The 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 PS 20–20 and ANSI A190.1 for lamina of glued-laminated beams (NIST 2020; APA 2017, 2013a).

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 18 includes a generic list of grademarks and practices for MSR, MEL, and E-rated lumber, although 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 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 ($\times 10^6$ 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 parallel to grain (lb/in^2); symbolism may vary slightly
E	abbreviation for MOE ($\times 10^6$ 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

Table 18—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.

are kept up to date. A complete listing of all machine stress grades is found in the *NDS Supplement—Design Values for Wood Construction*, NDS table 4C, design values for mechanically graded dimension lumber (AWC 2018, 2015, 2012; AF&PA/AWC 1997). 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, 1,500f–1.4E, 1,800f–1.6E, and 2,100f–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 et al. 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 1,500f–1.4E grade—the “bread and butter” grade of the 1960s for the metal-plate truss industry—was switched to 1,650f–1.5E. This was in response to changes

Table 19—Differences between machine-stress-rating (MSR) and machine-evaluated-lumber (MEL) grading techniques[a]

Characteristics	MSR	MEL
Quality control	Each piece must meet certain visual requirements before it can be assigned design values. Daily basis for average stiffness (a "minimum" or fifth percentile stiffness), strength property, and bending modulus of elasticity (MOE) in an edgewise orientation are required. The fifth percentile value is assigned as 82% of the average MOE assigned to the grade.	Requires daily quality control tests for tension strength in addition to the daily bending strength, stiffness tests, and visual assessment required for MSR. The fifth percentile stiffness value is assigned as 75% of the average MOE assigned to the grade.
Grade	The grade names include the fiber stress in bending (F_b) value and the average MOE value assigned to the grade.	The grade names are in letter format and digits.
Coefficient of variation	11%	15%

[a]Kretschmann (2010); Brown et al. (1997).

in the corresponding visual grade assignments and thus was necessary to maintain markets challenged by the visual grades.

Soon after the advent of the 1,650f 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 tabulation is a schematic example of the influence of width on commercial machine grades. The E values in the tabulation 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	2 by 4	2 by 6	2 by 8
1,800	1.7	1.8	1.9
2,100	1.9	2.0	2.1
2,400	2.2	2.3	2.4

Although based on actual test observations, this tabulation 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 this also challenges some traditional series combinations. Even for 2 by 4 lumber, the 2,400f–2.0E grade is suggested to become an actual 2,400f–2.2E grade, based on qualification. This may result from a more thorough qualification that examines both F_b (bending) and F_t (tension parallel to grain). If this occurs, a 2.2 mean grade E may be required to maintain the 2,400F_b and its traditional 1,925F_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 by Galligan et al. (1979), has been examined by research at the West Coast Lumber Inspection Bureau (Galligan and DeVisser 1998; Galligan et al. 1979). In summary, the 0.80 ratio of F_t/F_b used traditionally for assignment of properties to machine grades of 2,400F_b and higher is not always verified in qualification tests. Consequently, if the qualification test results in a ratio of 0.70, for example, the mill may choose to continue to market a 2,400F_b grade but assign a 1,680F_t value instead of the traditional 1,925F_t. A second option, assuming test verification, is to hold the traditional 1,925F_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 supply of the wood to a mill 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 2,400F_b/1,680F_t grade nor a 2,750F_b/1,925F_t grade. The choice for marketing communication and simplicity could be to continue to market a 2,400F_b/1,925F_t grade. However, if the test data require acknowledgment of a real F_t/F_b ratio of 0.70, the *grade-limiting* property will be 1,925F_t and F_b will actually be at the 2,750-lb/in^2 level (and maintained there), even though marketing requires stamps of 2,400F_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 tabulation 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 2,100f 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 lumbers. Therefore, 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 lumbers, 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, whereas, the test-based results only set the outside limits of the process.

This handbook can only point out the variables that can be observed in the process of assigning properties to machine grades. Each mill may have timber 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. All these factors are important in considering grade assignments.

Appendix D—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 0.10 lb. (To be consistent with the yield exercise of the text, the material in Appendix D 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 influenced by VQL. Practical rules for sampling must be adopted as the 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 E—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. However, how "rich" are the grades? What is the strength profile of each grade with respect to adjacent grades in the grading matrix? Is there a potential for improved yield or 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 this handbook in the subheading of "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 2,400f, 2,100f, 1,650f, and 1,450f.

1. Sample sizes arbitrarily selected for this example are 100 pieces each for 2,400f and 2,100f, 400 for 1,650f, and 200 each for 1,450f 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 times the design of the highest (2,400f) grade. Each grade below 2,400f 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 1,650f column under grade assignment. Of the 400 pieces tested, 67 survived the 2,400f proof level. Of those that failed the proof load, 101 were less than 2,400f in strength but equal to or better than the 2,100f proof level; whereas, 208 of the 1,650f pieces failed with test values that equaled or exceeded the 1,650f accept level but were less than the 2,100f proof level. Twenty-four pieces (6%) failed below the 1,650f accept level of 3,465 lb/in^2, suggesting that 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 2,400f, 2,100f, 1,650f, and 1,450f, respectively. The total strength "potential" of the lot is shown from the horizontal summations to be 18.6% for 2,400f and above, 18.8% for the 2,100f level, 27.4% for 1,650f and 22.6% for 1,450f, with 12.5% not meeting the 1,450f 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. In addition, 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 2,400f, if the proof load level were set to correspond to an assigned value for a 2,850f 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						
		2,400f	2,100f	1,650f	1,450f	Reject	Total	Performance
Test/criterion level								
Proof load level (2,400f × 2.1)	5,040	96	***33***	***67***	***9***	—	205	18.6% @ 2,400f or better
2,100f accept level	4,410	3	64	***101***	***39***	—	207	18.8% ≥ 2,100f but < 2,400f
1,650f accept level	3,465	1	2	208	***60***	***30***	301	27.4% ≥ 1,650f but < 2,100f
1,450f accept level	3,045		1	24	186	***38***	249	22.6% ≥ 1,450f but < 1,650f
Loads < 1,450f level	—				6	132	138	12.5% < 1,450f
Summary								
Total pieces		100	100	400	300	200	1,100	
% 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 2,400f. 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 F—Mill Arrangements for Grading Machines

Figures 18 to 25 illustrate arrangements of machines and essential auxiliary equipment that will permit estimating specific capital investment and installation costs. 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. Current machine grading equipment suppliers should be consulted for optimal installation arrangements to augment this appendix.

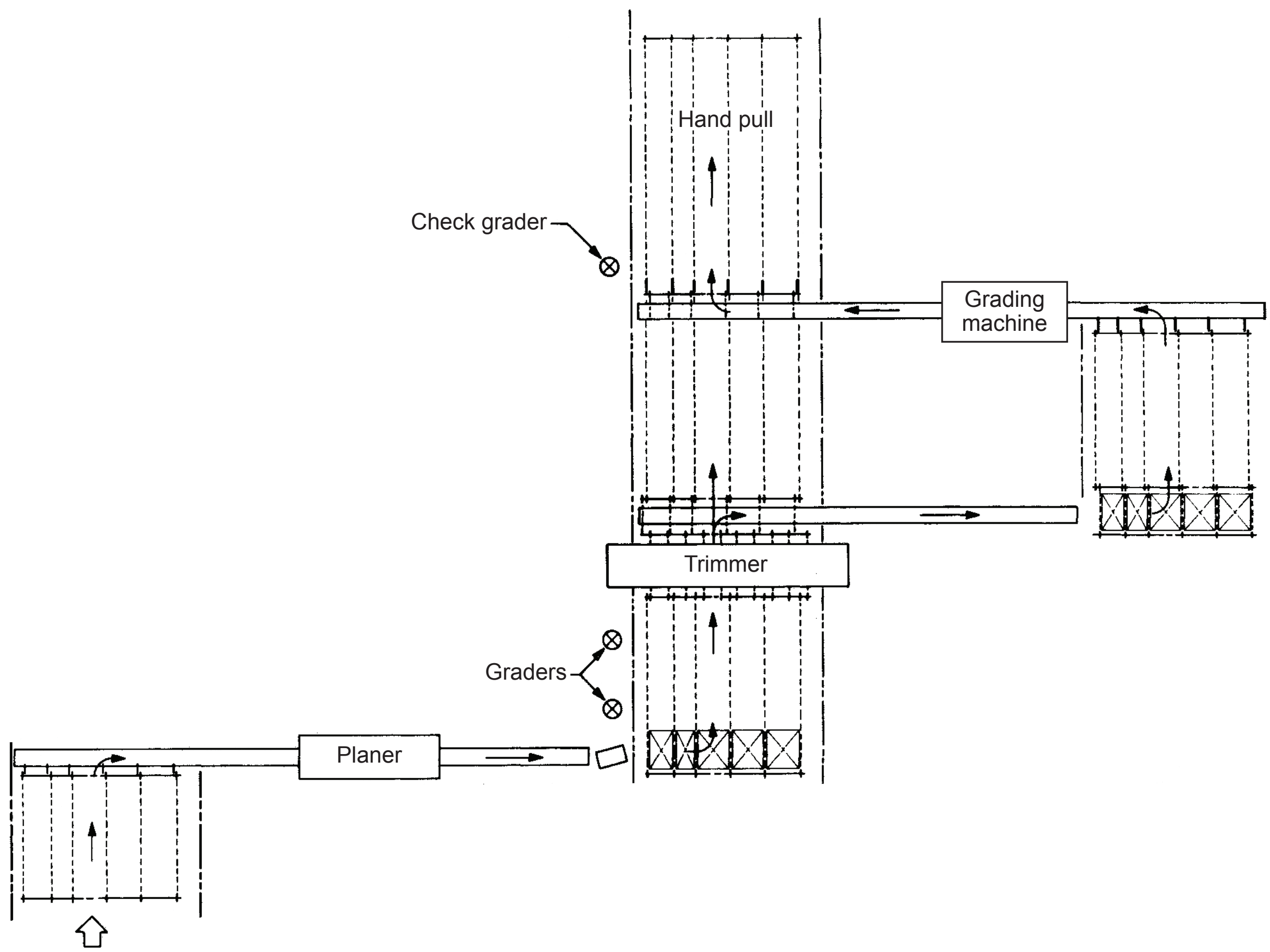

Figure 18—Basic planing mill arrangement for machine grading. Visual graders designate pieces to be routed through grading machine. Check grader follows machine grading and trimming operation to ensure correct grade output. Only a portion of lumber normally passes through grading machine.

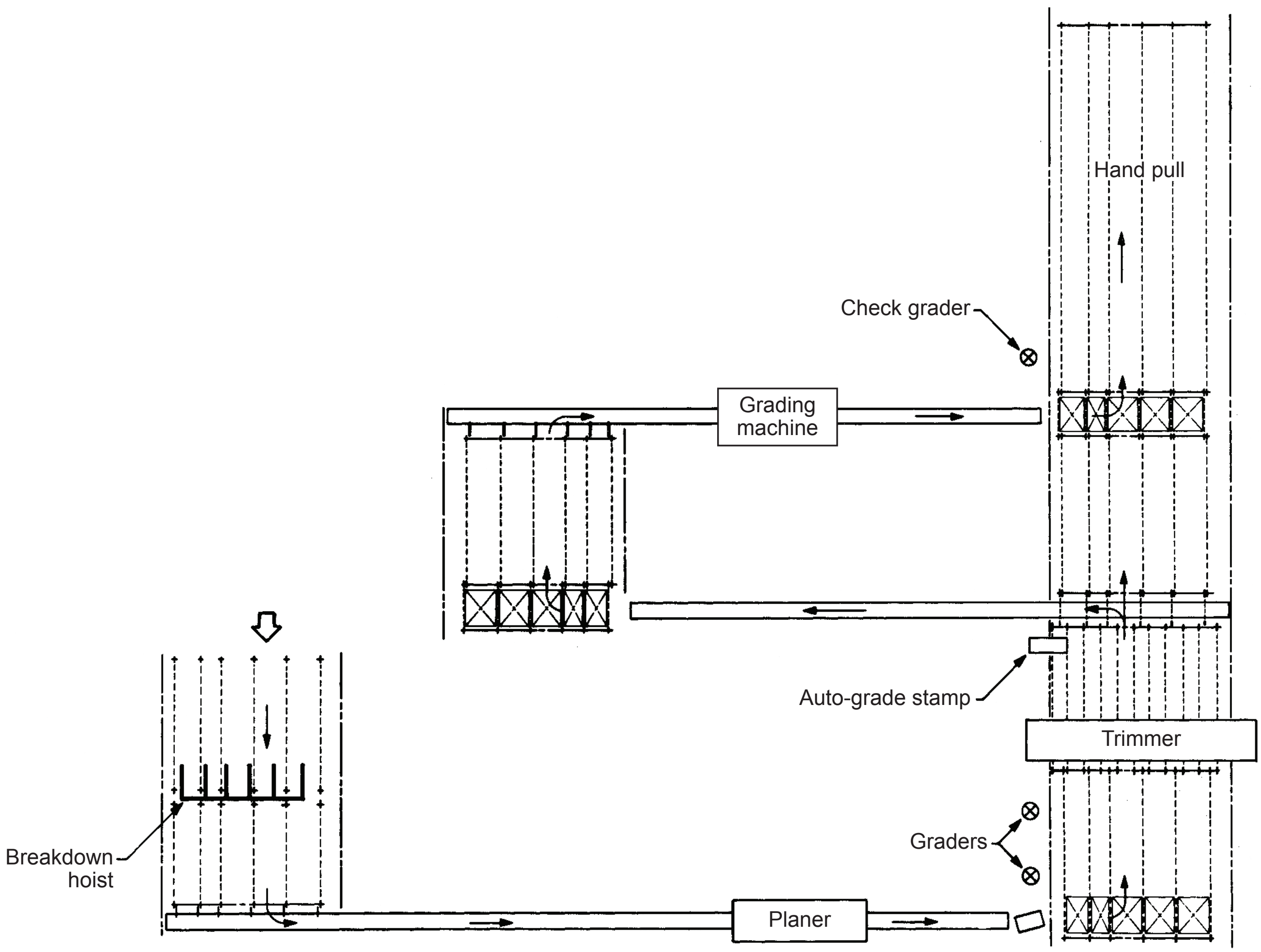

Figure 19—Mill grading arrangement modified from that of Figure 18 to incorporate automatic grading–trimming station that also controls lumber to be routed to grading machine.

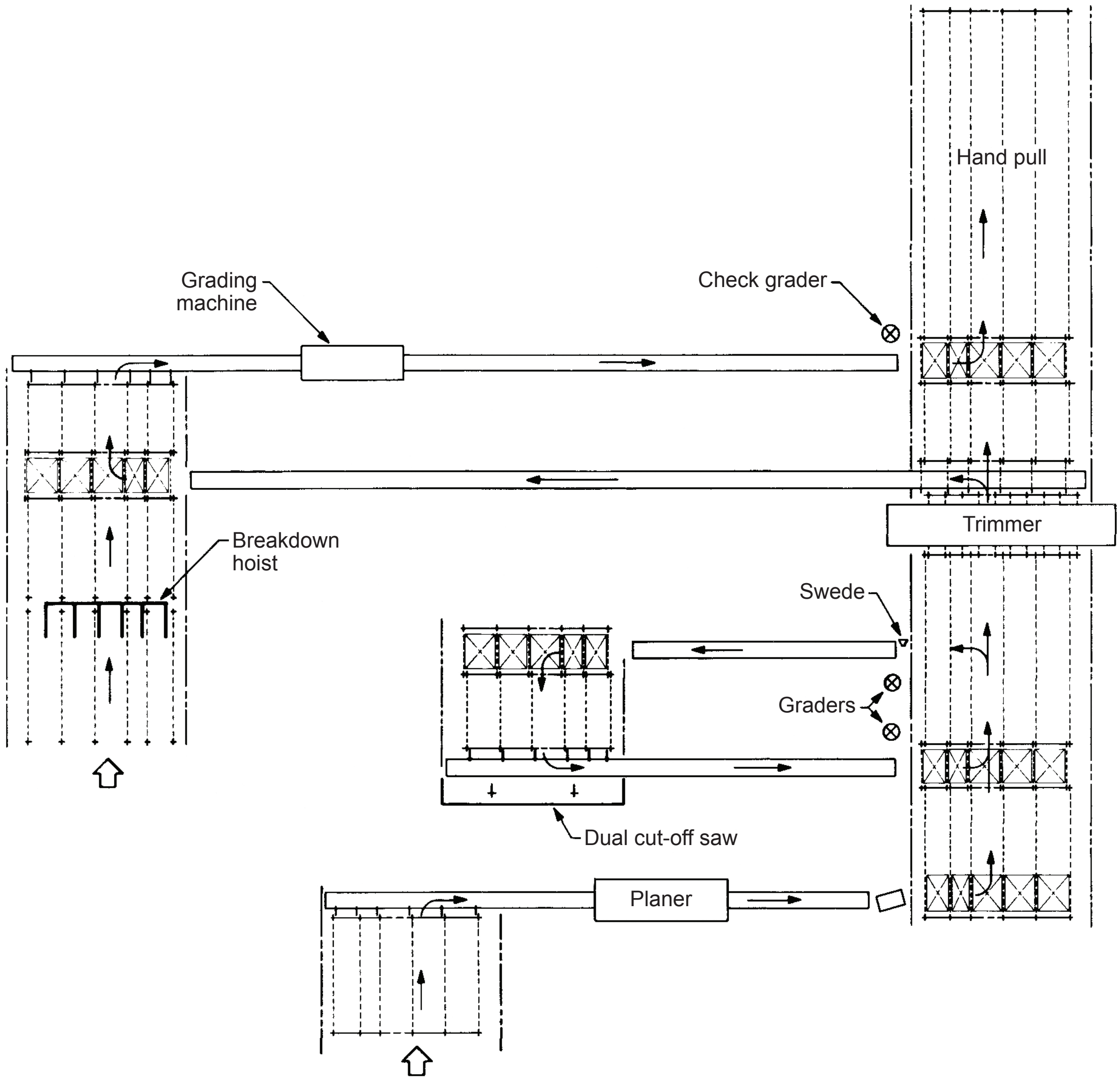

Figure 20—Planing mill arrangement in conjunction with grading machine. Graders can use cut-off saw to upgrade lumber prior to final visual or machine grading. Arrangement includes separate breakdown hoist that permits machine grading independent of standard planing–grading–trimming operation.

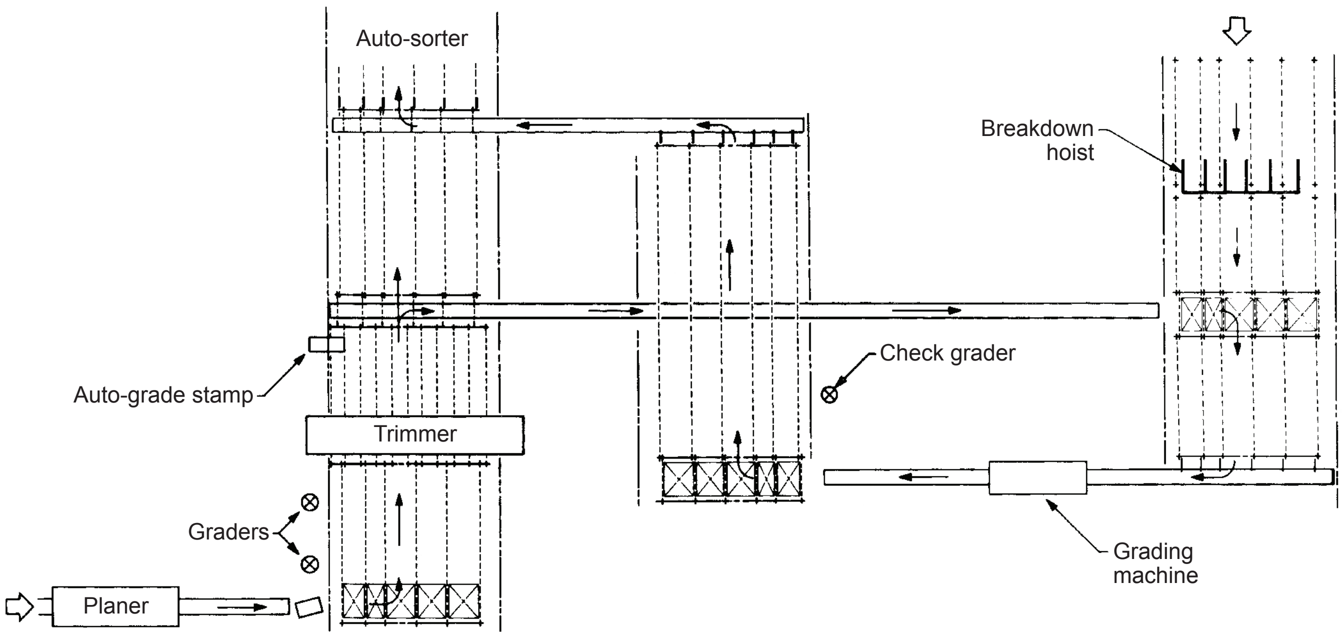

Figure 21—Grading operation in conjunction with automatic grading, trimming, and sorting. Separate breakdown hoist adds flexibility to installation.

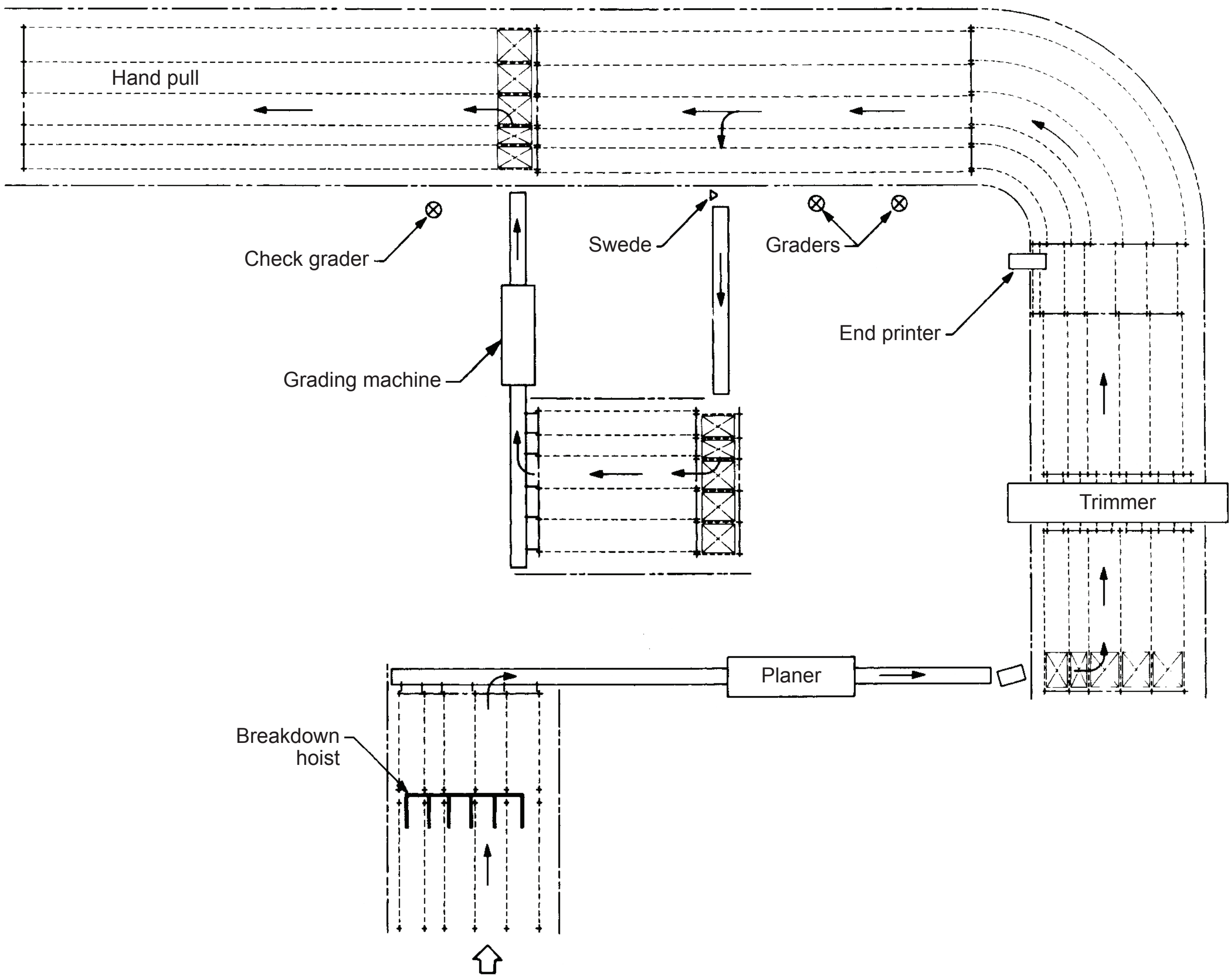

Figure 22—Planing mill arrangement in which graders hand-select pieces to be routed by swede to grading machine.

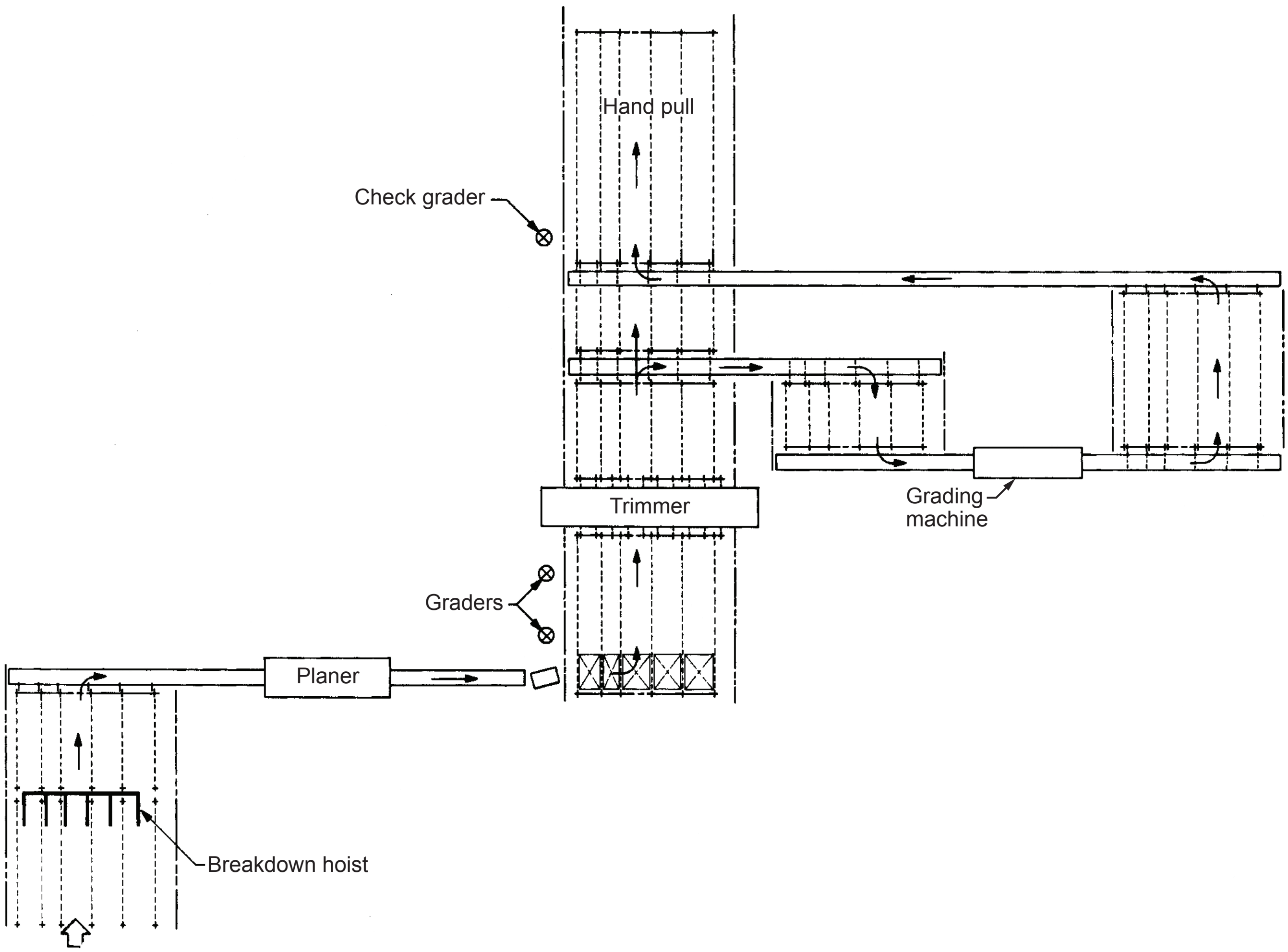

Figure 23—Grading arrangement illustrating variation in equipment for routing lumber from dry chain through grading machine and back to check grader.

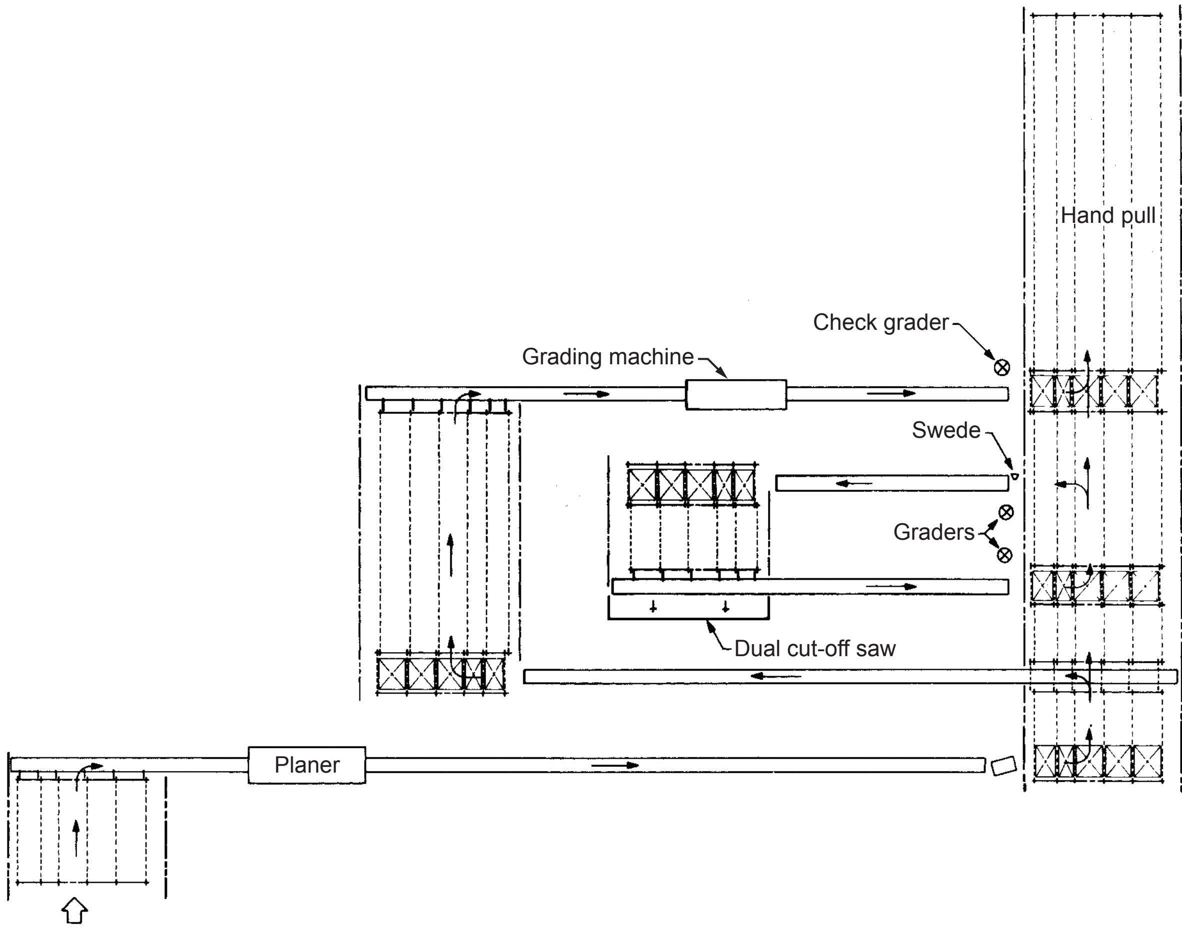

Figure 24—Planing–grading operation in which all trimming is handled by a dual cut-off saw.

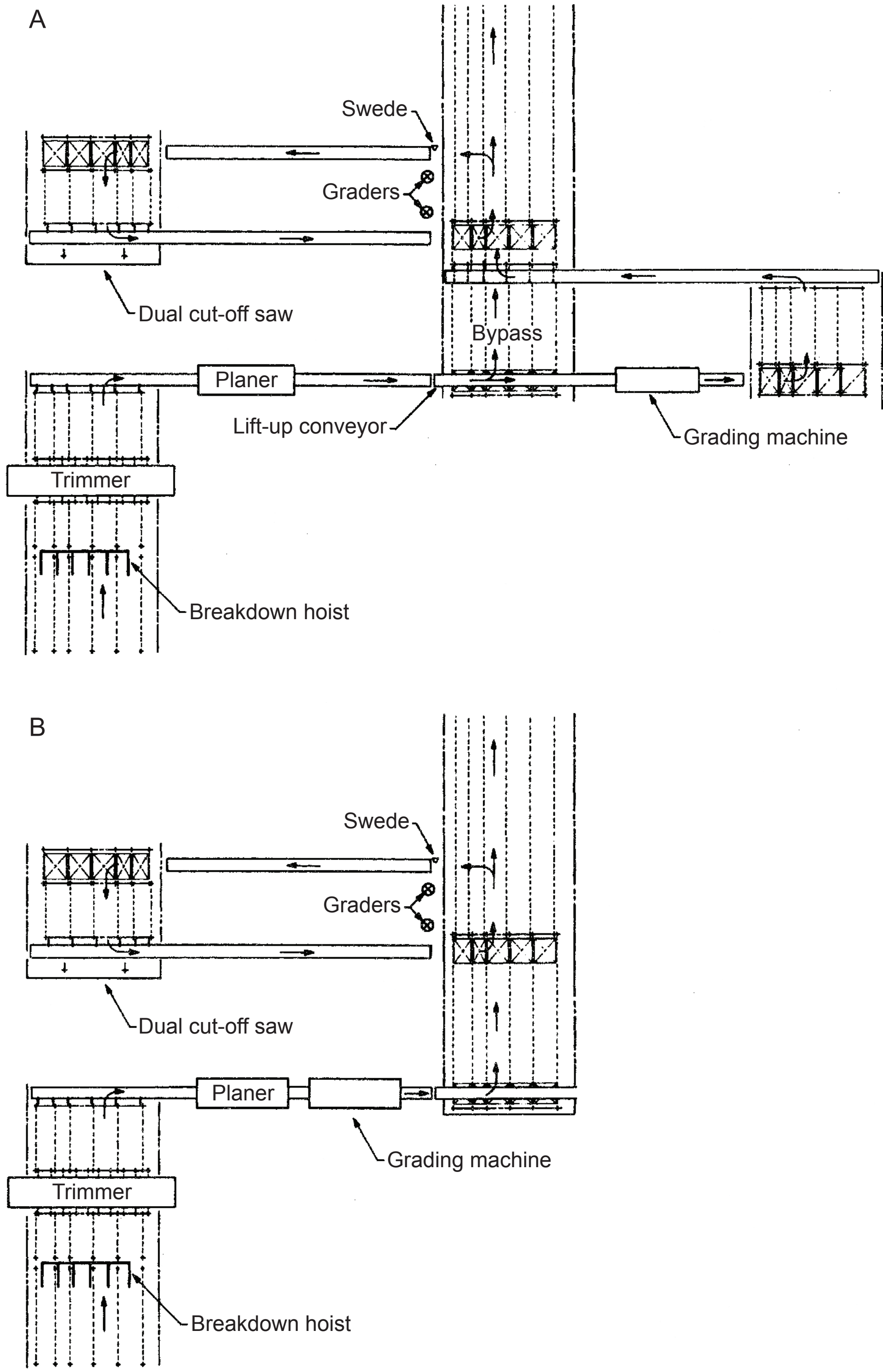

Figure 25—Planing mill arrangement in which all lumber is trimmed before planing and passed through the grading machine as standard procedure. The by-pass (A) permits mill operation with visual grading if the grading machine is out of operation or is not needed. (B) illustrates close coupling to the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