SIRT

Strategic Integrated Research in Timber

Edinburgh Napier UNIVERSITY

introduction to strength grading

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In association with

The Wood Technology Society

A Division of the Institute of Materials, Minerals and Mining

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2015

Variation

- From species to species
- Within species / species group
  - Between countries
  - Within countries
  - Within a forest
  - Within a stand
  - Between trees in a stand
  - Within a tree
  - Within a board
  - Depending on how the board is loaded

Variation of properties

& correlation between properties

Structural engineering design

- About buildings
  - Staying safe
  - Staying fit for use
- Dealing with uncertainty
  - Of material
  - Of the actions on a structure
  - Of analysis and construction
- <u>True irrespective of the material</u>

(There is always some uncertainty)

Limit states (Eurocode)

- Ultimate limit state (ULS)
  - Safety of the people and the structure
  - Collapse, or need for major repair
  - Infringement is serious
- Serviceability limit state (SLS)
  - The structure remaining functional
  - And the comfort of the people
  - Infringement is less serious

Dealing with uncertainty

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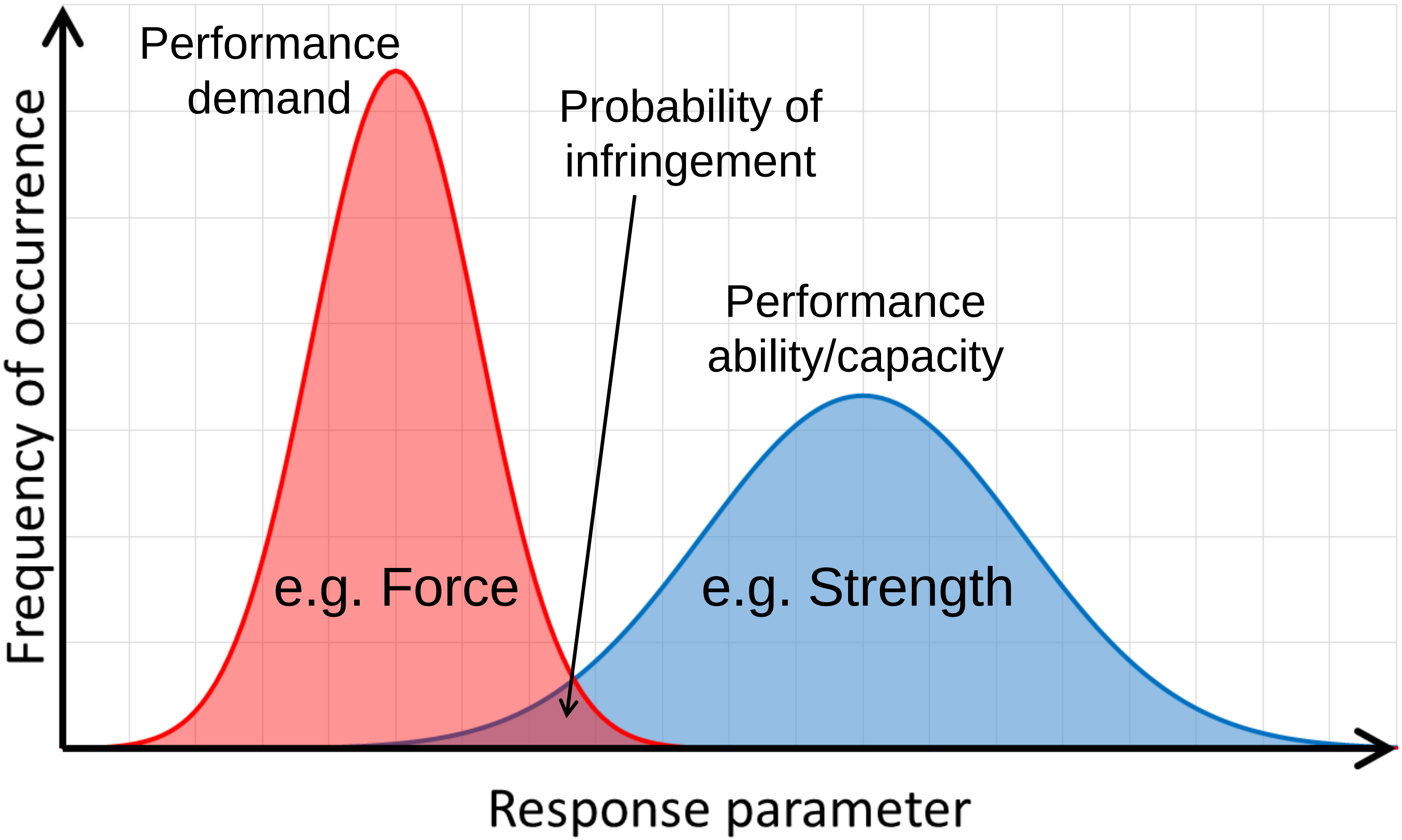

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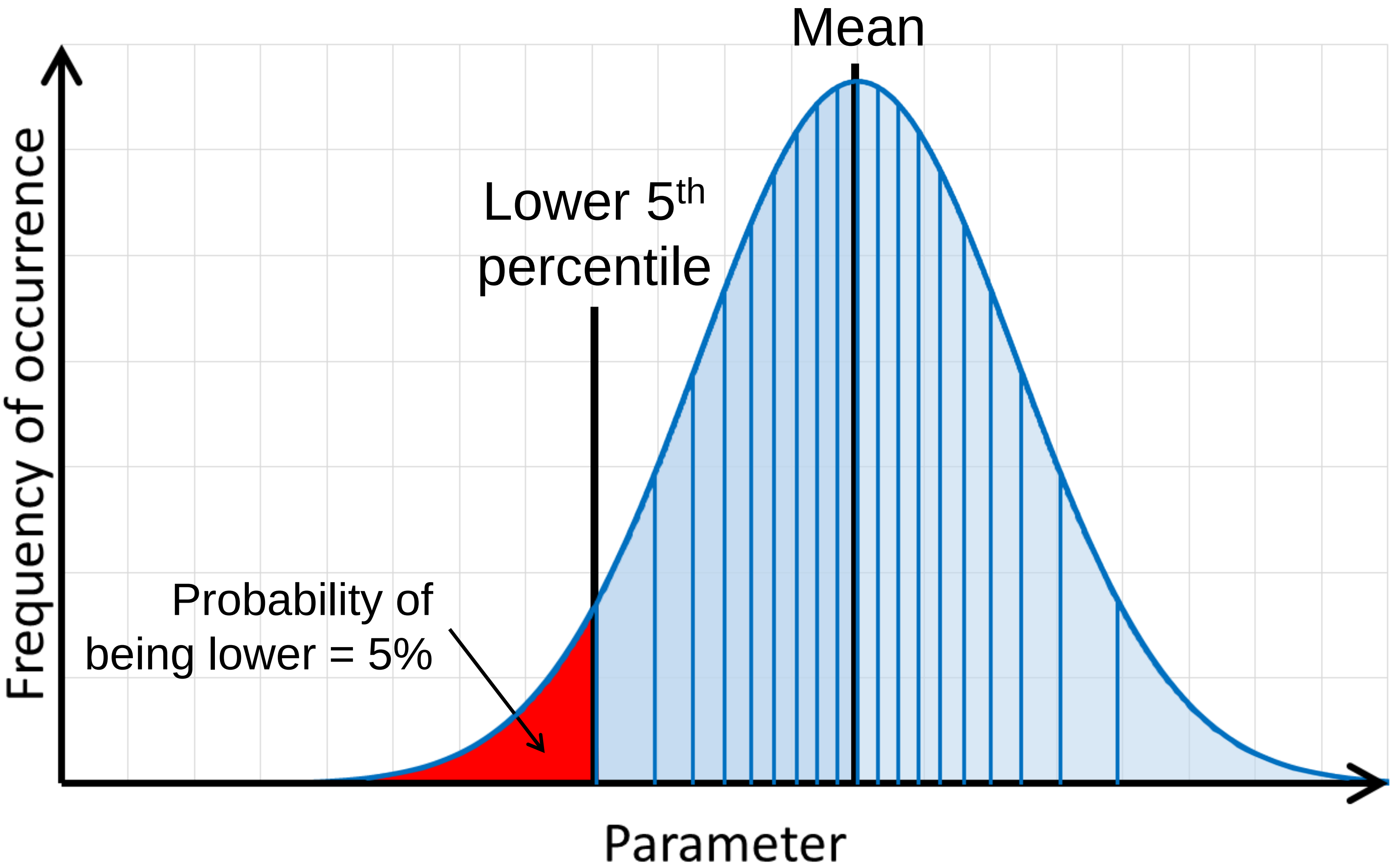
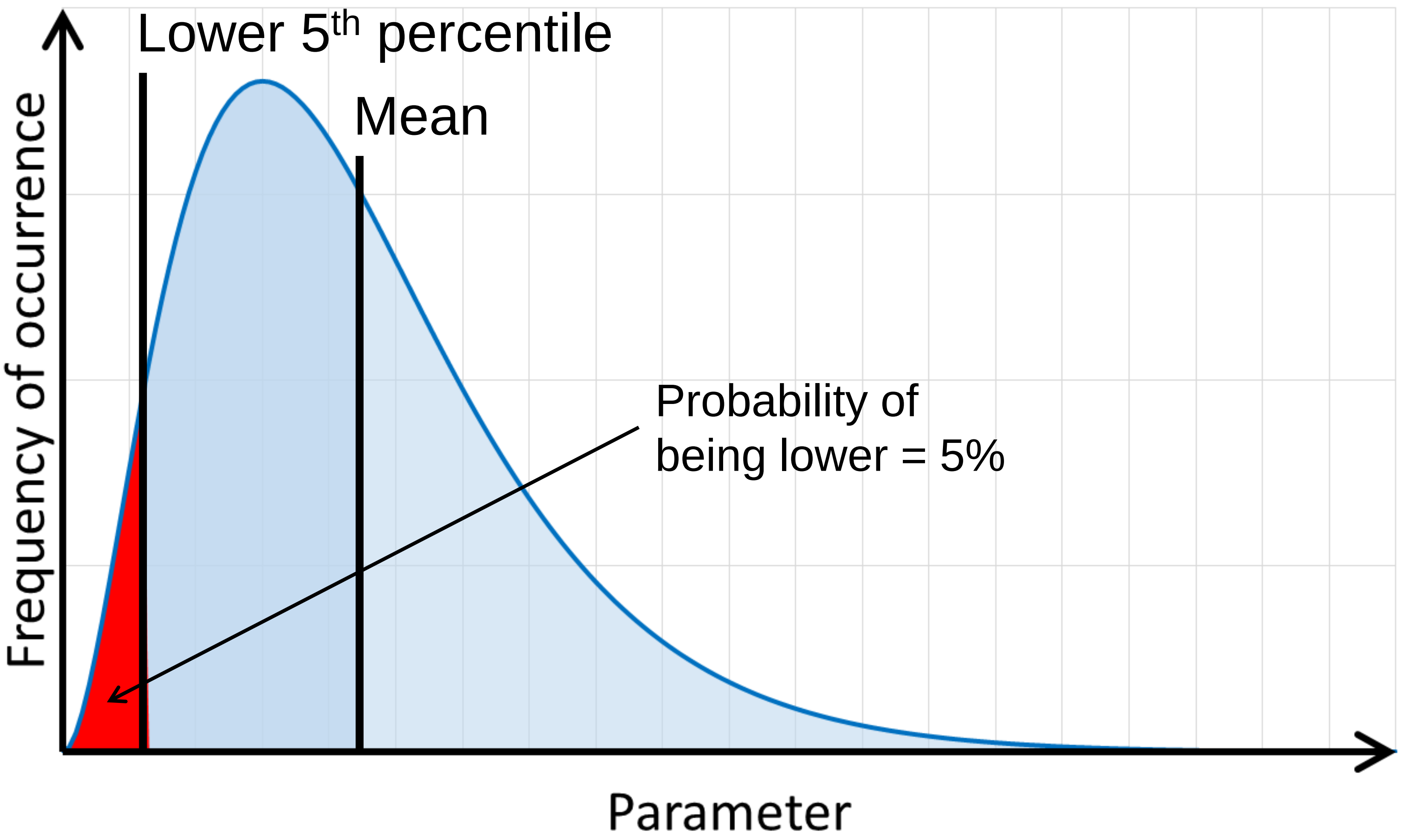
Characteristic values



Characteristic values



EN338:2009		Softwood species										
		C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45
Strength properties (in N/mm^2)												
Bending	$f_{m,k}$	14	16	18	20	22	24	27	30	35	40	45
Tension parallel	$f_{t,0,k}$	8	10	11	12	13	14	16	18	21	24	27
Tension perpendicular	$f_{t,90,k}$	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
Compression parallel	$f_{c,0,k}$	16	17	18	19	20	21	22	23	25	26	27
Compression perpendicular	$f_{c,90,k}$	2,0	2,2	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3,1
Shear	$f_{v,k}$	3,0	3,2	3,4	3,6	3,8	4,0	4,0	4,0	4,0	4,0	4,0
Stiffness properties (in kN/mm^2)												
Mean modulus of elasticity parallel	$E_{0,mean}$	7	8	9	9,5	10	11	11,5	12	13	14	15
5 % modulus of elasticity parallel	$E_{0,05}$	4,7	5,4	6,0	6,4	6,7	7,4	7,7	8,0	8,7	9,4	10,0
Mean modulus of elasticity perpendicular	$E_{90,mean}$	0,23	0,27	0,30	0,32	0,33	0,37	0,38	0,40	0,43	0,47	0,50
Mean shear modulus	G_{mean}	0,44	0,5	0,56	0,59	0,63	0,69	0,72	0,75	0,81	0,88	0,94
Density (in kg/m^3)												
Density	ρ_k	290	310	320	330	340	350	370	380	400	420	440
Mean density	ρ_{mean}	350	370	380	390	410	420	450	460	480	500	520

Grades and classes

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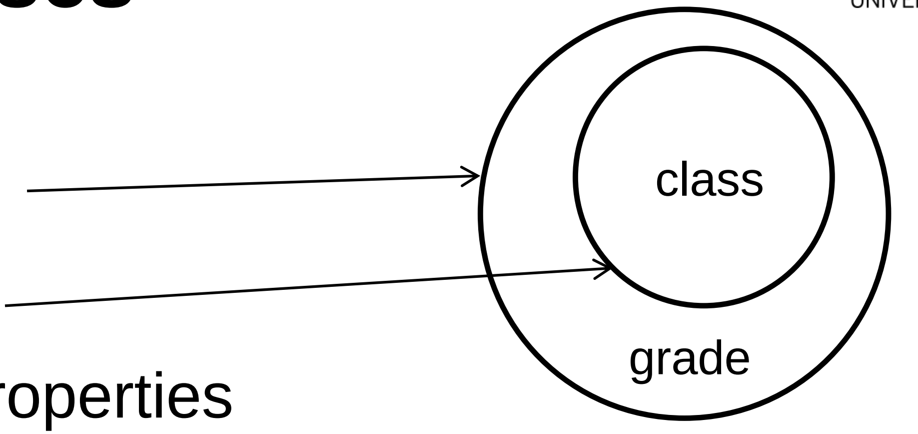

- Strength grade
- Strength class
  - Has numerical properties
- Timber grades are assigned to a class
- EN 338 lists strength classes
- C classes for softwoods (but see later…)
- D classes for hardwoods
- These are not the only strength classes

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A comparison factor

BS5268

(a permissible stress code)

EC5

(a limit state code)

short-term characteristic strength

global safety factor

long-term permissible strength

DOL (duration of load)

long-term characteristic strength

material factor γ_M (= 1.3)

long-term design strength

long-term design loads

load factor γ_F (= 1.35 to 1.5)

long-term characteristic loads

Comparison factor: permissible stress = $\dfrac{\text{DOL}}{\gamma_M \times \gamma_F} \times \left(\text{characteristic strength}\right)$

Grade-determining properties

- Strength
  - Usually major axis bending strength
- Stiffness
  - Usually major axis bending stiffness
- Density
  - Also an indirect measure of strength in some elements of timber design
- All the other strength class properties are derived from these 3 main properties
  (By conservative relationships. Equations are in EN 338, but will be moved to EN 384)

ULS

SLS
(sometimes ULS)

Critical property

- Grades are defined by characteristic
  - Strength (lower 5th percentile)
  - Stiffness (mean)
  - Density (lower 5th percentile)
- The limits are general across species
  - Softwoods (C classes...major axis bending)
  - Hardwoods (D classes...major axis bending)
  - Density (lower 5th percentile)
- Other strength class systems exist

EN338:2009

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Critical property

- To comply with the grade, characteristic values must be met (at least*)
- For a species and grade combination usually one property is limiting
  - Strength
  - Stiffness
  - Density
- So strength grading isn't *always* about predicting strength

* subject to adjustments

How do we predict strength?

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- Can only be measured destructively
- But strength is correlated with:
  - Stiffness
  - Density
  - Knots
  - Grain e.g. ring width
    - Rate of tree growth & radial position
  - Species
  - Origin

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How do we predict stiffness?

- Stiffness can be measured non-destructively
  - Mechanical bending (within elastic range)
  - Dynamic stiffness (vibration or time of flight)
- It is also correlated with
  - Density
  - Knots
  - Grain e.g. ring width
    - Rate of tree growth & radial position
  - Species
  - Origin

How do we predict density?

- Density can be measured non-destructively
  - By weighing and measuring dimensions
  - Using x-rays (and similar methods)
  - Pin indent
  - But is confounded by moisture content
- It is also correlated with
  - Stiffness
  - Grain e.g. ring width
    - Rate of tree growth & radial position
  - Species
  - Origin

Grading methods for timber

- Visual strength grading
  - (not the same as appearance grading)
- Machine strength grading
  - Machine control
  - Output control

Visual strength grading

- Manual inspection (can be machine assisted)
- Based only on what we can see (and infer)
- Of limited accuracy…
  …due to the parameters being measured
  …and the human element
  …so assignment to grades is more conservative
- A slow process using trained people
  - But can be assisted…perhaps even done by machine
- But grading can be verified (mostly) afterwards
- Still very common in Europe even for softwoods

Visual strength grading

- Overarching requirements in EN 14081-1
- But done according to National Standards
  - BS 4978 (softwoods)
  - BS 5756 (hardwoods)
  - Also German, Canadian, French, Italian, Dutch, Nordic, Spanish...
- Assignments to classes in EN 1912
- According to testing to EN 384
- Can also be assignments elsewhere

Visual grading

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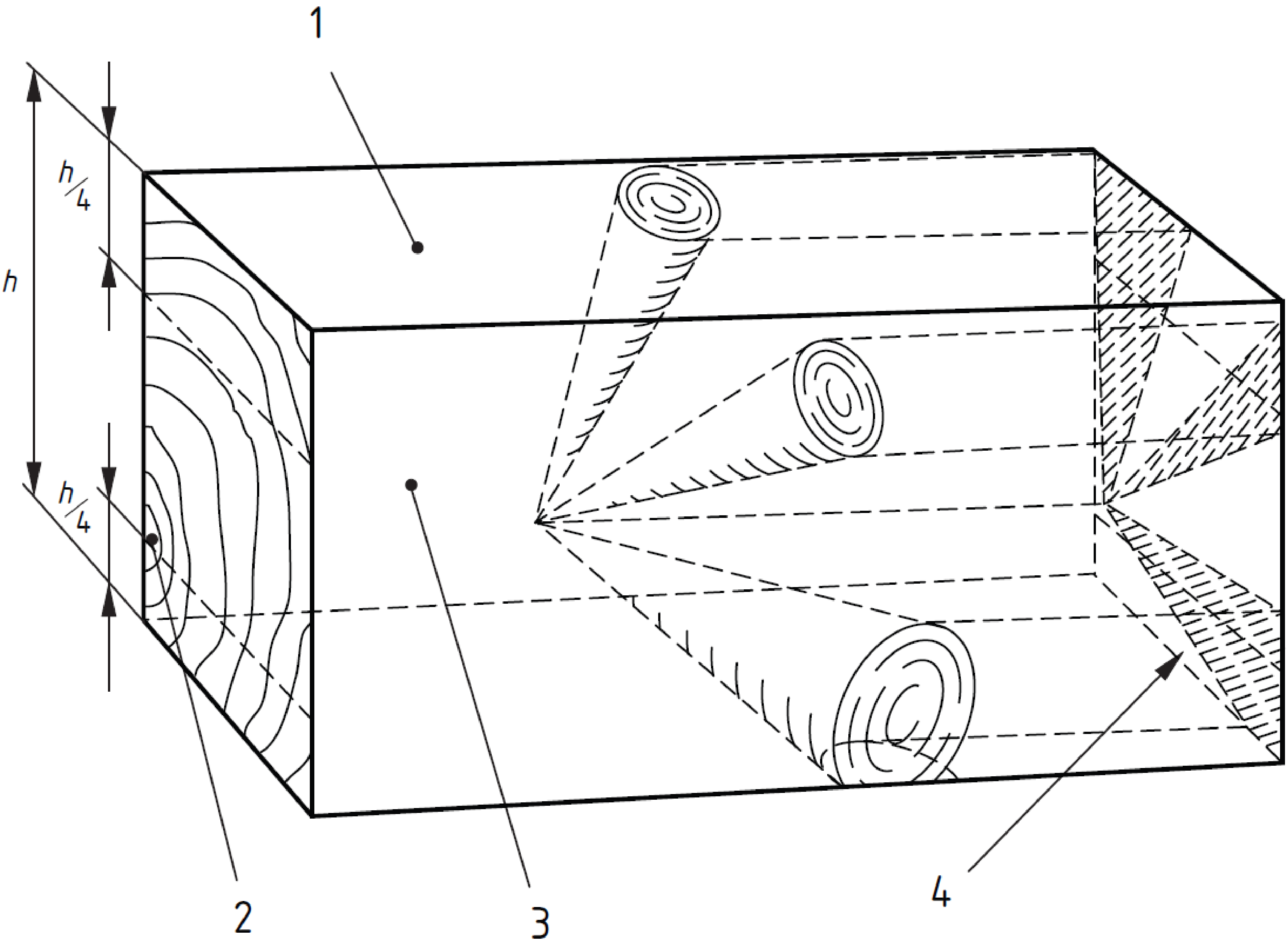

Visual strength grading

- Visually grade
  - e.g. SS, GS (softwoods to BS 4978)
- Assign to strength class based on grading standard, species and origin
  (all three must match)
  - EN 1912
    - e.g. British spruce SS → C18
    - e.g. British spruce GS → C14
  - Somewhere else (not in conflict with EN 1912)
- Based on testing and analysis to EN 384
  - Not supposed to rely on long standing practice any more …need test data

EN 1912:2012

Strength Class	Grading rule publishing country	Grade (see Note 2)	Species commercial name	Source	Botanical identification (see Table 3)	Comments
C35	Germany & Austria	S13, S13K	Douglas Fir	Germany & Austria	54	
C30	France	ST-I	Spruce & Fir	France	1, 22	
	Germany, Austria & Czech Republic	S13, S13K S13, S13K S13, S13K S13, S13K	Spruce Pine Fir Larch	CNE Europe CNE Europe CNE Europe CNE Europe	22 47 1 15	
	Italy	S1	Douglas fir	Italy	54	Maximum width and thickness 100 mm
	Nordic countries	T3 T3 T3 T3	Pine (Redwood) Spruce (Whitewood) Fir Larch	NNE Europe NNE Europe NNE Europe NNE Europe	47 22 1 15	

Machine strength grading

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- Machine grading
  - Relates an 'indicating parameter' to the critical grade-determining parameter(s)
  - Better accuracy than visual grading…
    …due to the parameters being measured
    …and the automation
    …so assignment to grade is less conservative
  - Fast but expensive equipment (but getting cheaper)
  - Cannot really be verified afterwards

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What? Cannot be verified?

- Timber should be labelled so that the strength class is clearly indicated
- But it is not possible to tell if an individual piece has been correctly assigned to a strength class
- Because a piece can correctly belong to any strength class

How can that make sense?

- Timber grading does not operate on a piece by piece basis
- Pieces are individually assigned to grades
- …but it is the population of timber in that grade that matters
- And how it is assigned to the grade depends on the machine operation
- Packages of timber should meet the characteristic values
- (true also for visual grading – but you can check that the visual rules were applied correctly)

So does this make timber bad?

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- No!
- In fact this applies for all materials
- There is always some uncertainty
  - the variability is accounted for in design code
  - by characteristic values and partial safety factor γ_m

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Strength classes are distributions

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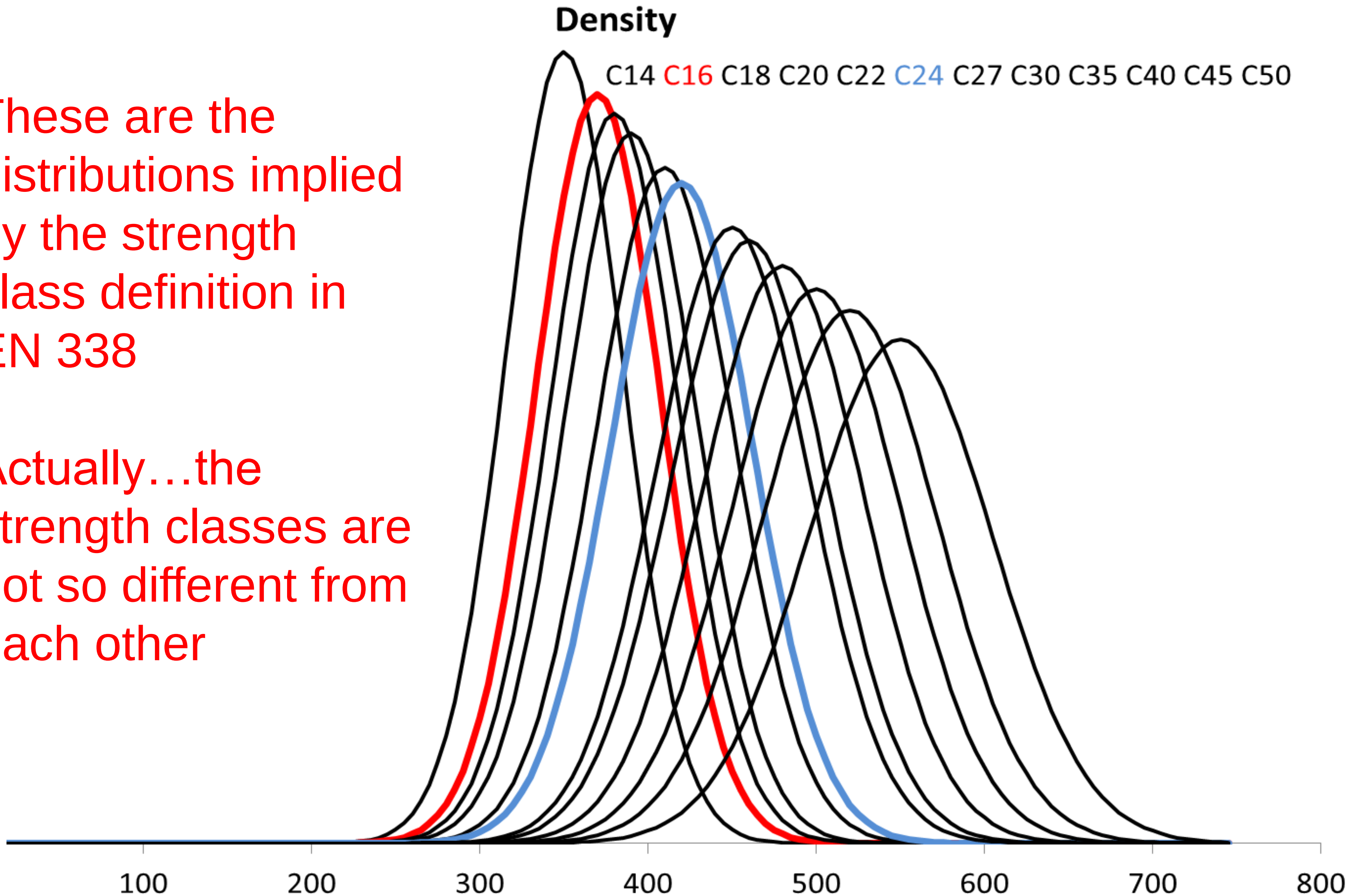
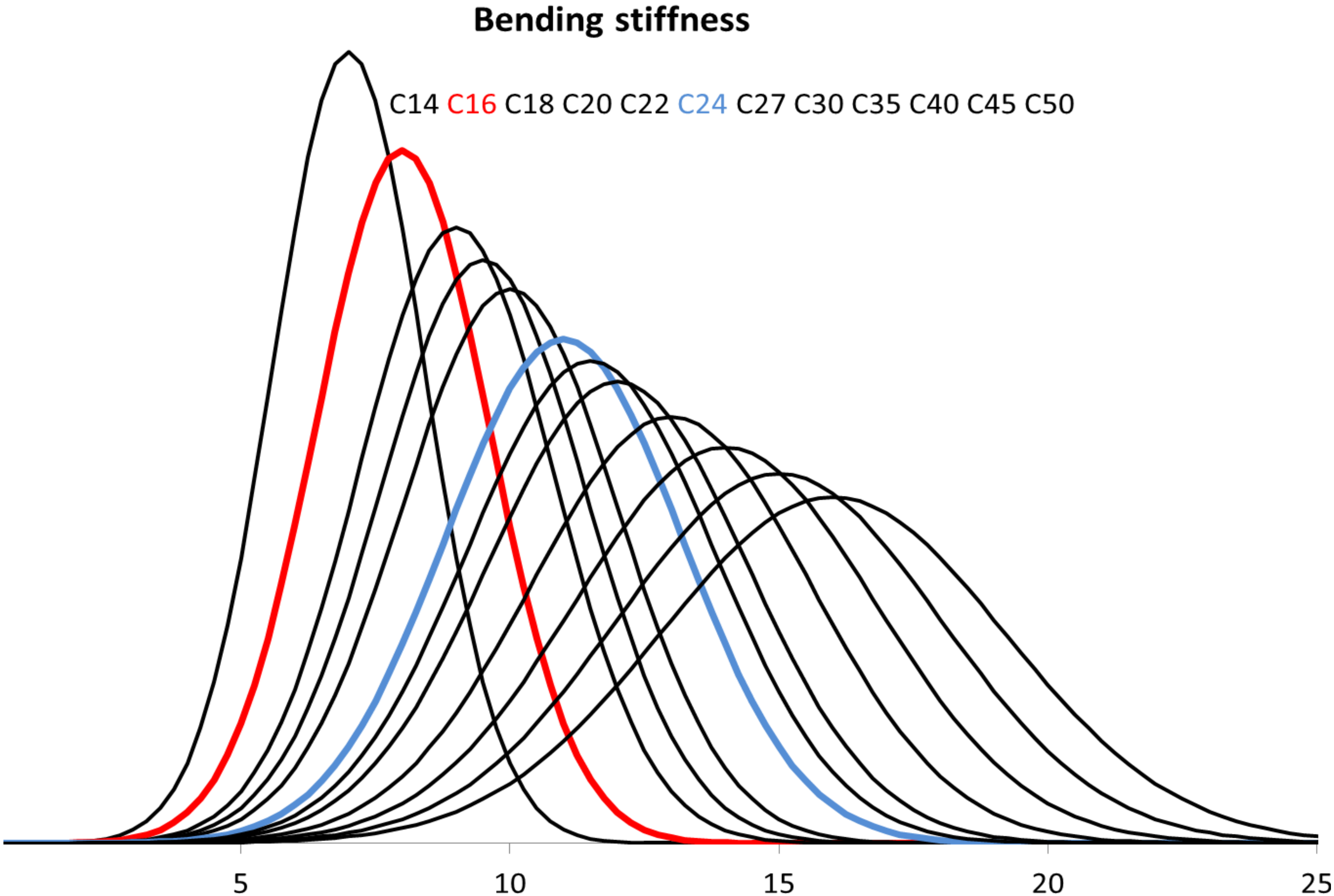
These are the distributions implied by the strength class definition in EN 338

Actually…the strength classes are not so different from each other



Strength classes are distributions



So how do we machine grade?

- Now many types of grading machines
  - Bending stiffness
    - Bending about the minor axis
  - Dynamic (acoustic/vibration)
    - Essentially a measure of stiffness
    - May or may not include density
  - X-rays
    - A combination of knots and density
    - Perhaps with optical camera
  - Assessment of slope of grain
  - Mixtures of the above

The indicating property (IP)

- Ideally want a good predictor of the critical grade-determining property
- Generally, additional measures improve IP
- But... it's a compromise with cost

- …and if your timber resource is better than the strength class you are grading to, you don't need the IP to actually do much – just identify the worse pieces

Approved grading machines

- Many devices can predict grade-determining properties
- …but that does not make them grading machines
- Machines must meet requirements of EN14081
- To ensure operation is reliable
- …including the human element

Bending graders

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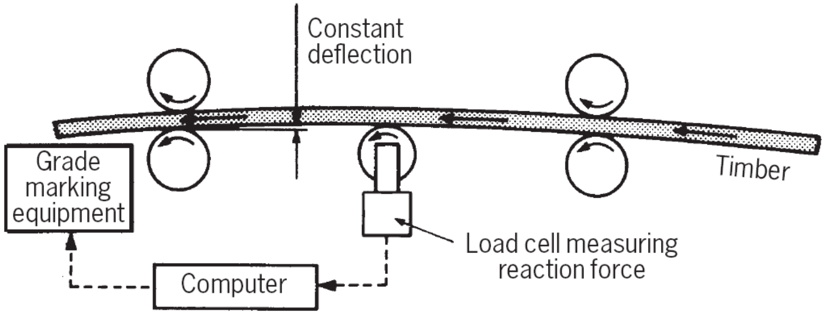
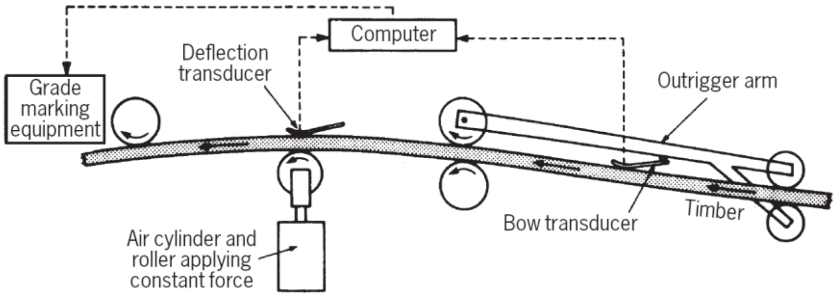
- Measure mechanical stiffness
  - Through application of defined load
  - or defined deflection
  - Minor axis
  - Accounting for pre-existing bow
- Relatively slow (with dynamic errors)
- Limited by cross-section
- Cannot measure the whole piece
- Older technology (hard to link to computers)

Bending graders

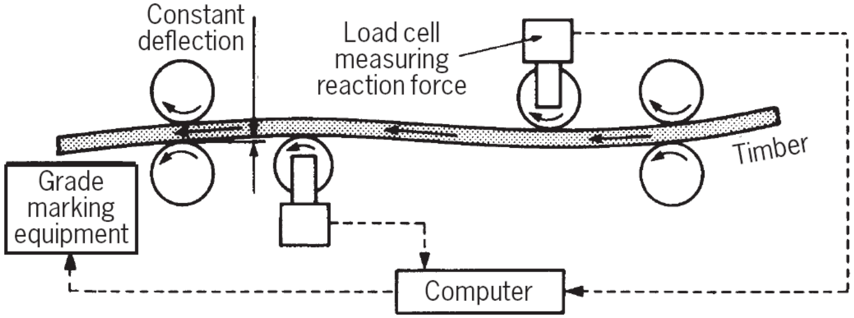
Cook-Bolinder



Computermatic



Timgrader



Figures from BRE Digest 476 "Guide to machine strength grading of timber"

Acoustic graders

- Measure acoustic velocity
  - Through axial or transverse vibration
  - Or time of flight (including ultrasonic)
  - May or may not include density ($MoE_{dyn} = \rho v^2$)
- Fast
- Can be hand-held
- Measure the whole piece
- …but all at once

Acoustic graders

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ViSCAN (MiCROTEC)

MTG (Brookhuis)

Precigrader (Dynalyse AB)

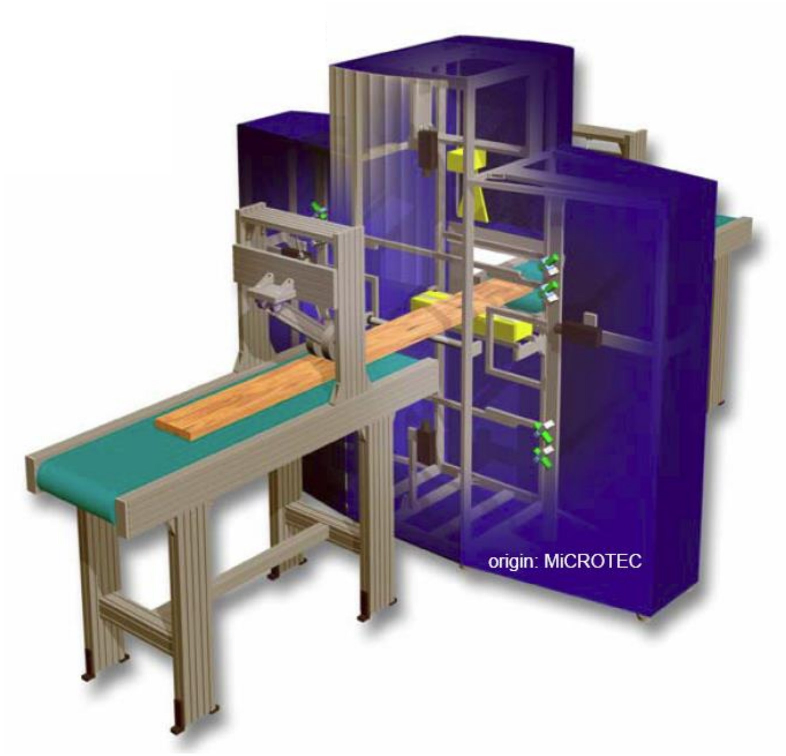
Triomatic (CBS-CBT)

X-ray graders

- Measure
  - Clear wood and average density
  - Knot size and location
- Very fast (and permit board splitting)
- …but big and expensive
- Measure the whole piece
- …and all parts of it individually
- But not great at predicting stiffness

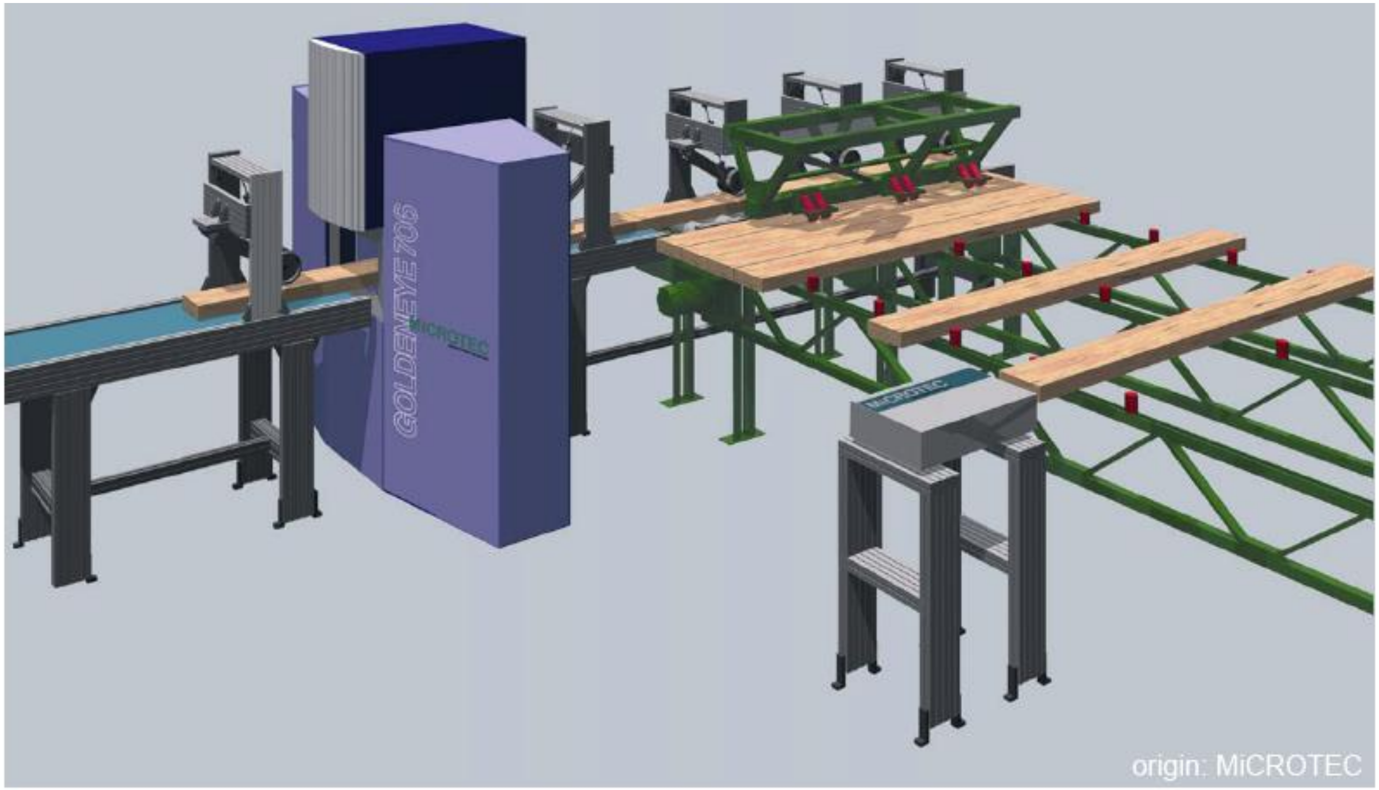
X-ray graders

GOLDENEYE 702 (MiCROTEC)



Combination graders

GOLDENEYE 706 (MiCROTEC)



But that's not everything yet

- "Visual" override
  - Distortion (might be by machine)
  - Fissures
  - Wane (note that genuine wane does not cut the grain)
  - Soft rot and insect damage
  - Knots and slope of grain on any portion that cannot be machine graded (i.e. the ends of the timber for bending type machines)
  - Anything else that causes concern

Two types of machine grading

As things currently stand

- Output control
  - Periodic testing of output
  - Testing element is costly
  - But adapts the machine settings to optimise yield
  - Idea: some initial testing + continuous testing
- Machine control
  - Can be done without need for testing of output
  - Relies on strict assessment and control of machines
  - No regular fine adjustment of machine settings
  - Idea: large initial testing programme

Output control

As things currently stand

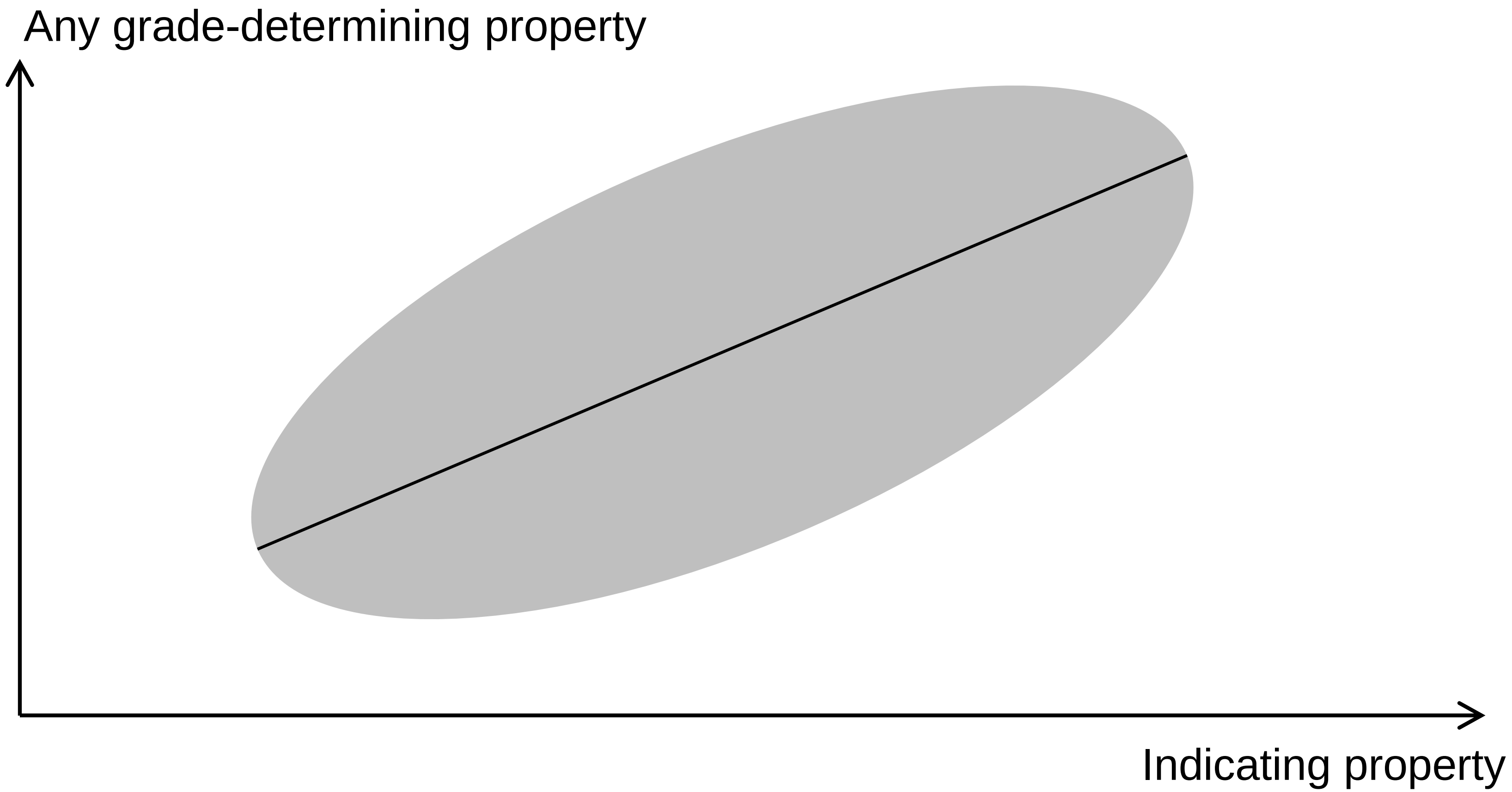
- Initial settings
  - Random sample of 60 pieces per grade
- Regular proof testing
  - ~ 5 pieces per grade per shift
- Adjust settings accordingly (by “CUSUM”)
  - Reduce pass rates when quality falls
  - Increase pass rates when quality rises

Machine control

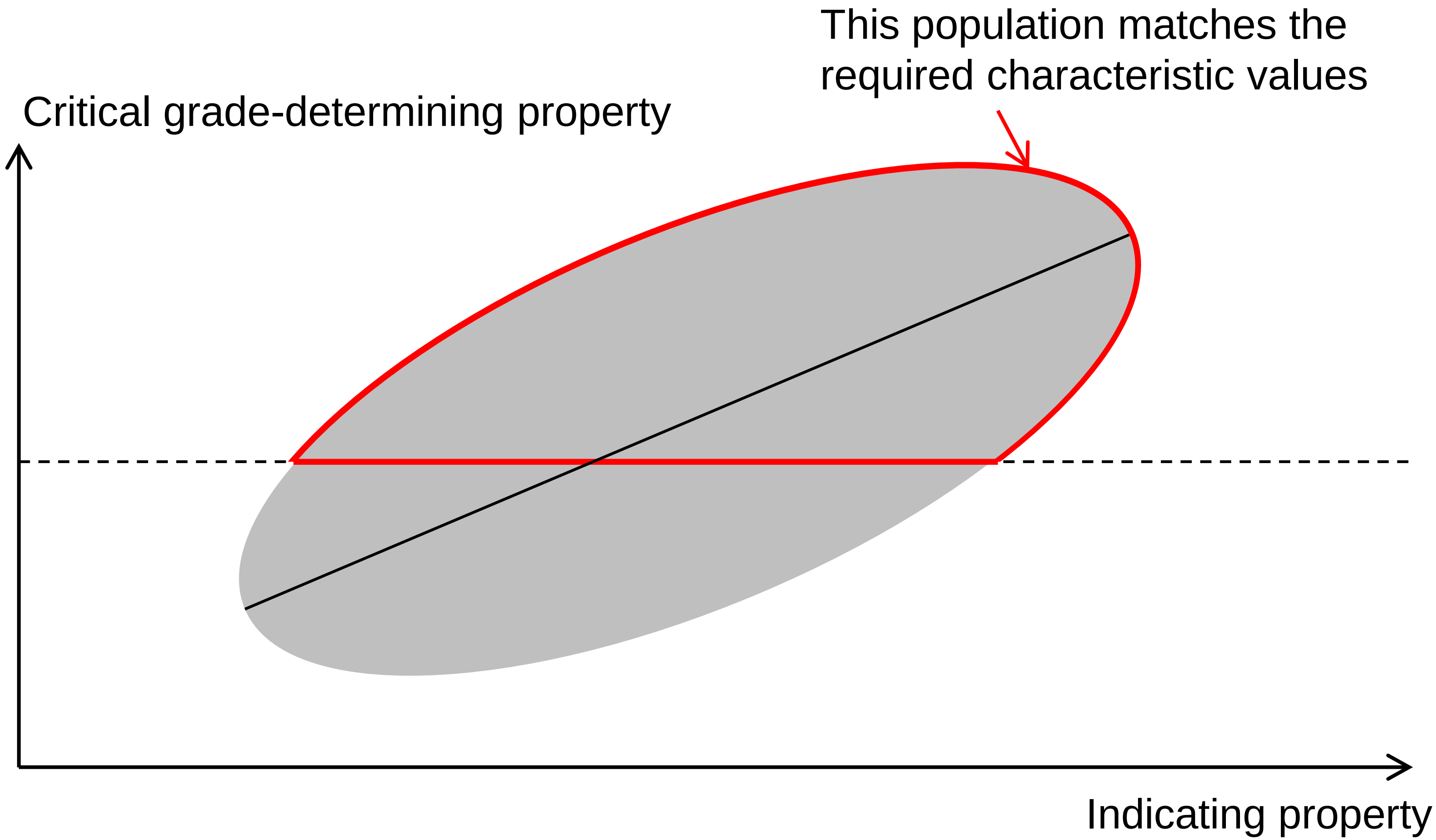
As things currently stand

- Initial testing
  - Representative sample of > 450 pieces
  - Covering the whole growth area
- Report produced for CEN TC124 WG2 TG1
  - Assessed
  - If approved,
    settings made available by machine manufacturer and passed to SG18 (Notified bodies)

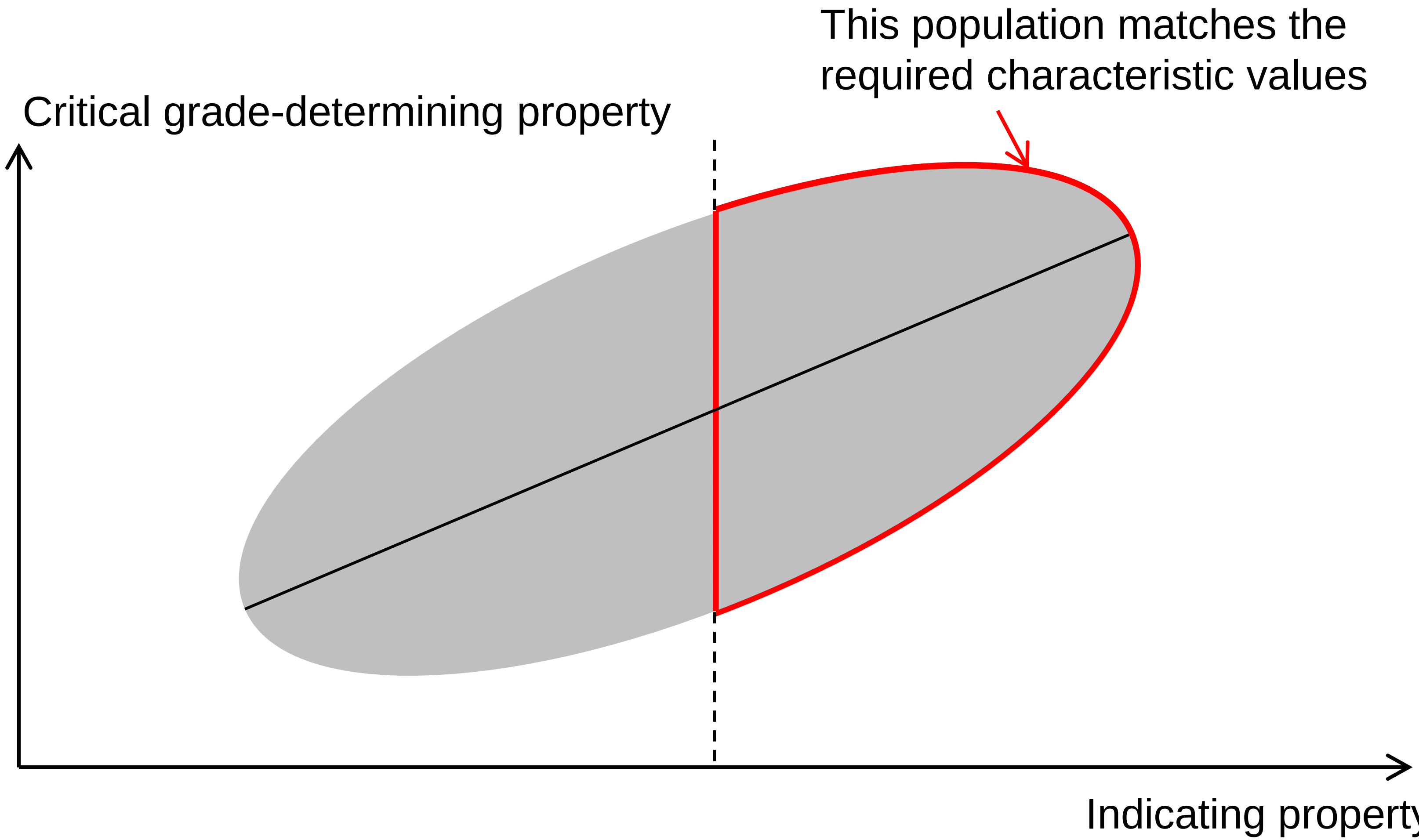
The results…



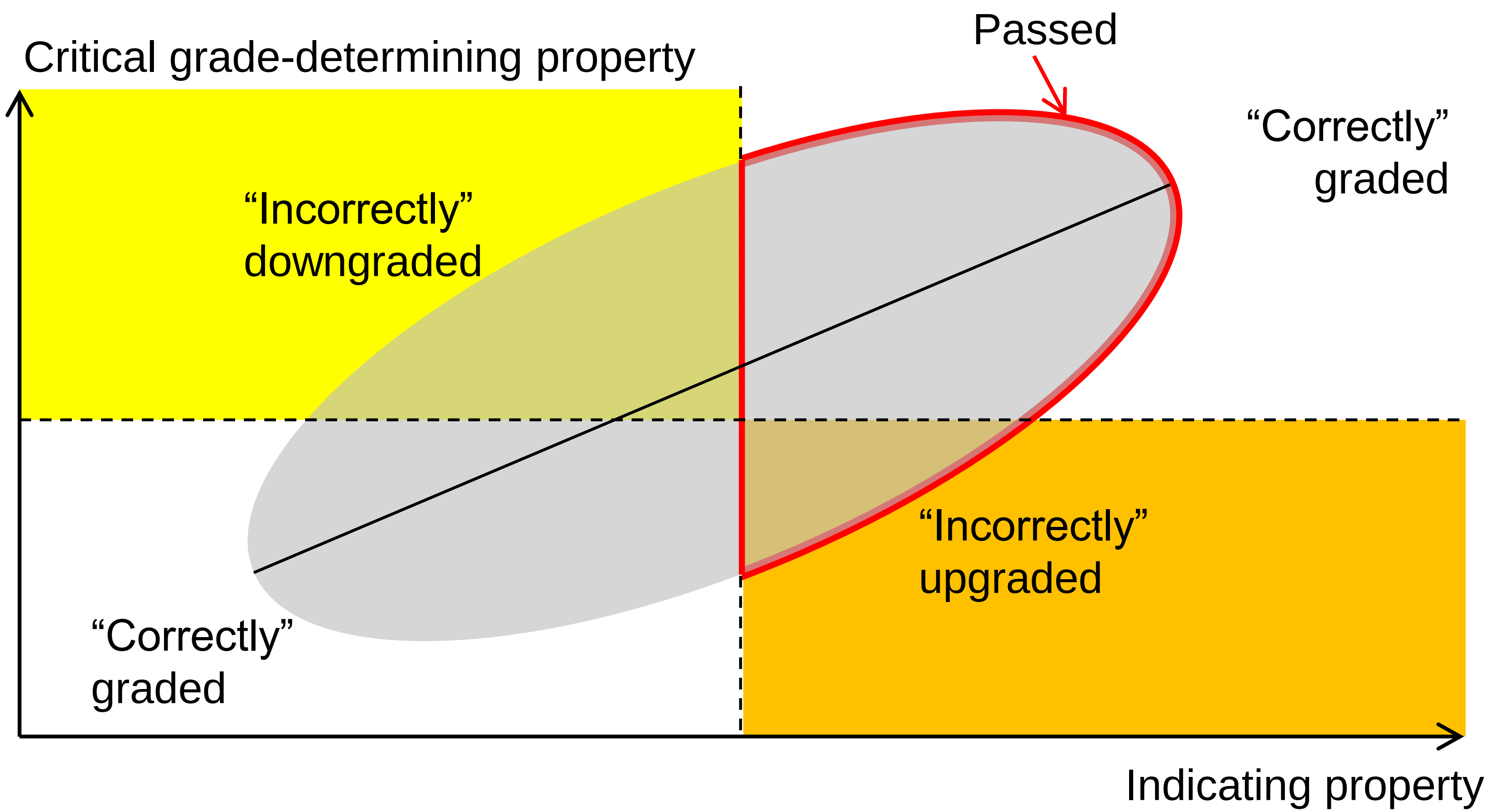
Optimum grade



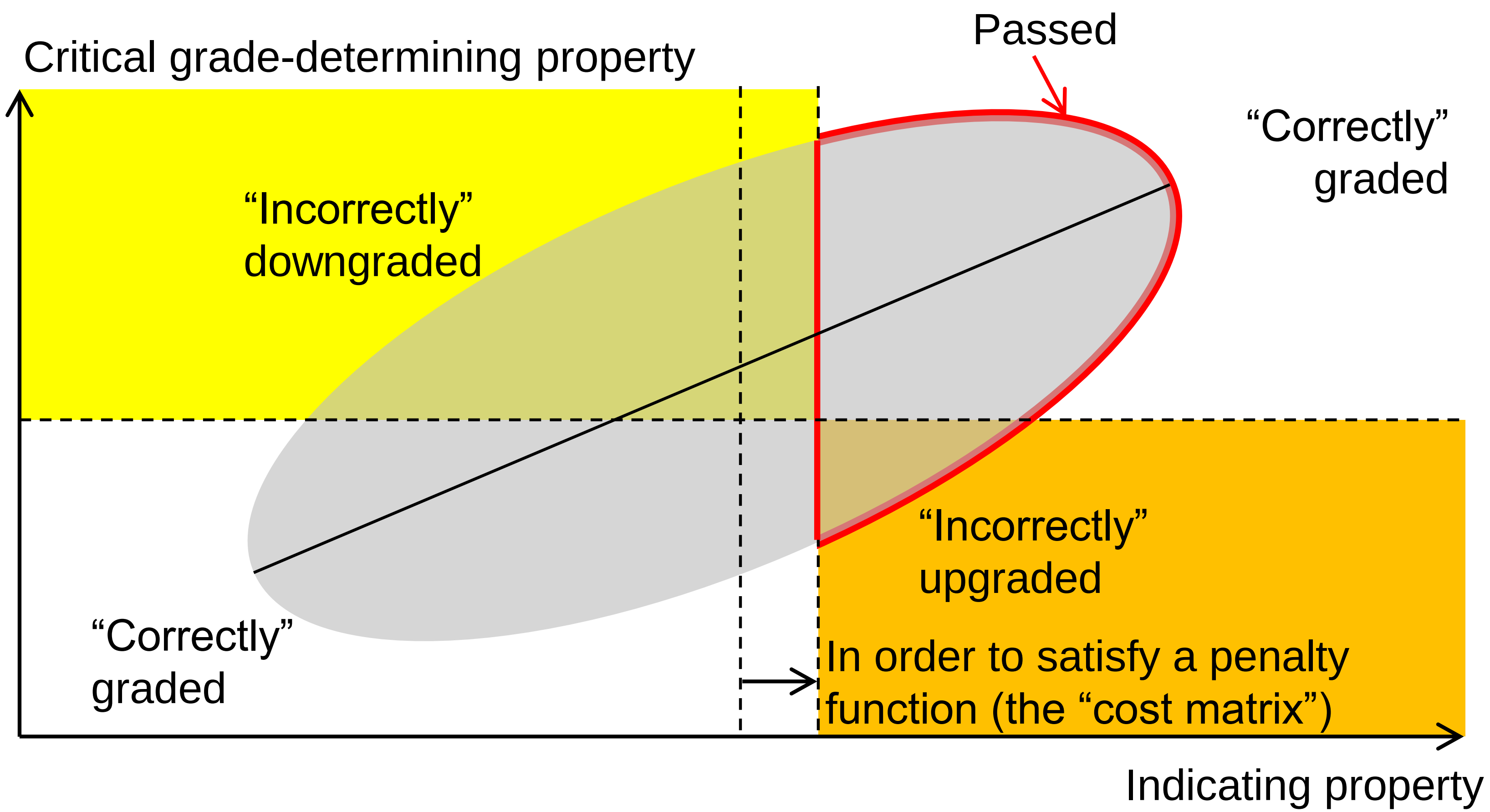
Using IP


This population matches the required characteristic values
Critical grade-determining property
Indicating property

Cost matrix


Passed
Critical grade-determining property
"Correctly" graded
"Incorrectly" downgraded
"Incorrectly" upgraded
"Correctly" graded
Indicating property

Cost matrix



Passed
Critical grade-determining property
"Correctly" graded
"Incorrectly" downgraded
"Incorrectly" upgraded
"Correctly" graded
In order to satisfy a penalty function (the "cost matrix")
Indicating property

Why a powerful IP is better

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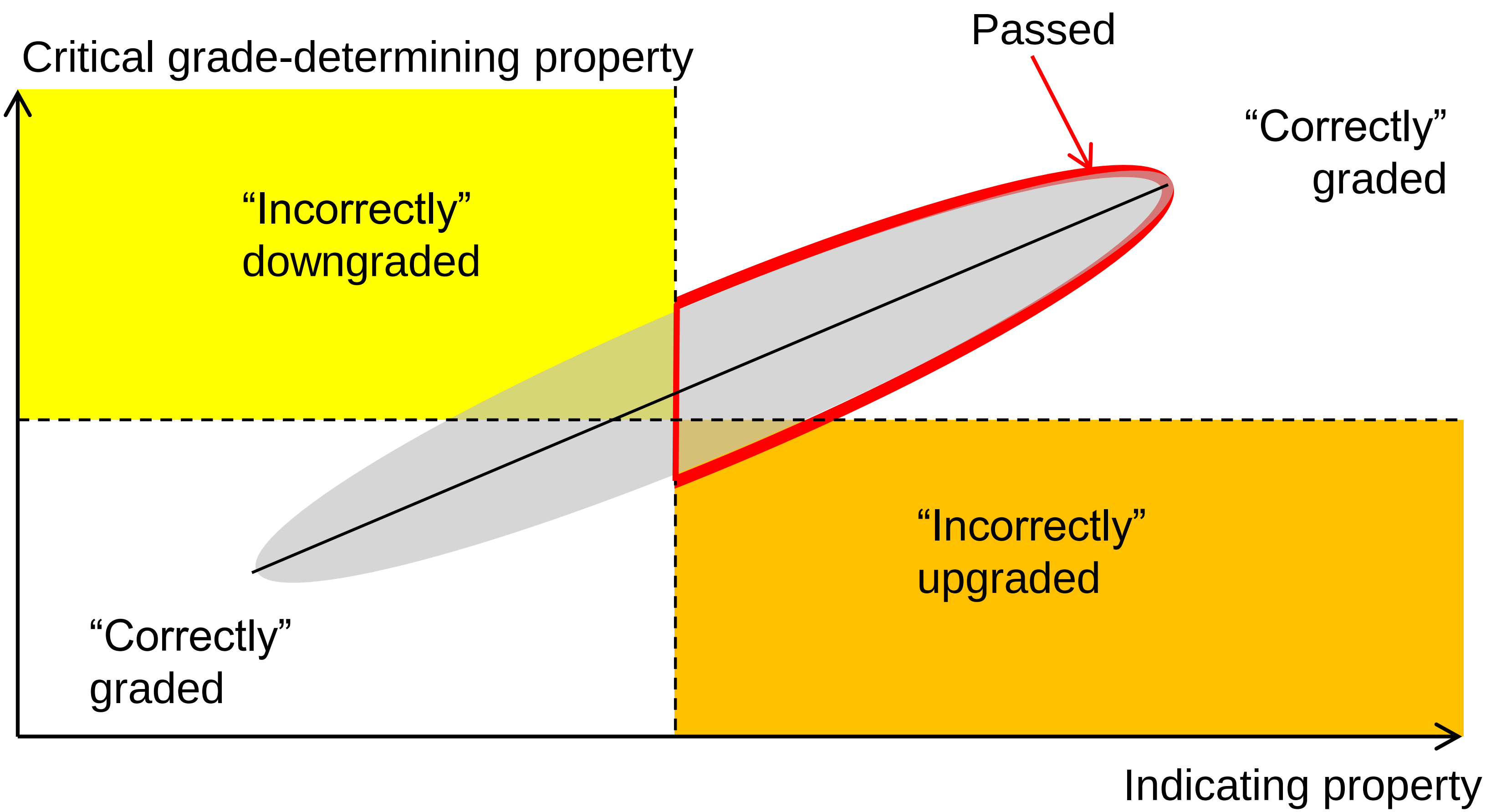

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The core standards

EN 14081, Timber structures - Strength graded structural timber with rectangular cross section

Part 1: General requirements

Part 2: Machine grading, additional requirements for initial type testing

Part 3: Machine grading; additional requirements for factory production control

Part 4: Machine grading; grading machine settings for machine controlled systems

No longer useful

BS 4978, Visual strength grading of softwood. Specification

BS 5756, Visual strength grading of hardwood. Specification

EN 336, Structural timber - Sizes, permitted deviations

EN 338, Structural timber - Strength classes

EN 1912, Structural timber - Strength classes - Assignment of visual grades and species

EN 408, Timber structures - Structural timber and glued laminated timber - Determination of some physical and mechanical properties

EN 384, Structural timber - Determination of characteristic values of mechanical properties and density

EN 14358, Timber structures - Calculation of characteristic 5-percentile values and acceptance criteria for a sample

+ CEN TC124 TG1 additional requirements

The bodies

- **CEN TC124** “Timber Structures”
  - WG1 “Test Methods”
  - **WG2 “Solid Timber”**
    - **TG1 “Grading”**
      - Approves machine settings, and assignments in EN 1912
- BSI B/518 “Structural Timber”
- UKTGC “UK Timber Grading Committee”
- SG18 “Sector Group 18” (Notified Bodies)

Summary

As things currently stand

- Two types of timber grading
  - Visual
  - Machine (machine control and output control)
- About building safety
- Based on mathematics of uncertainty
- …and test data
- Grading does not operate on a piece by piece basis
- Grading is not proof-loading