A discussion on the control of grading machine settings with regard to EN 14081

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Foto: Michael Meuter / LIGNUM

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ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

EMPA
Materials Science & Technology

Development of an efficient scheme for timber machine strength grading

- Close collaboration between

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

EMPA
Materials Science & Technology

- duration: 2007 - 2010

- Research Team:

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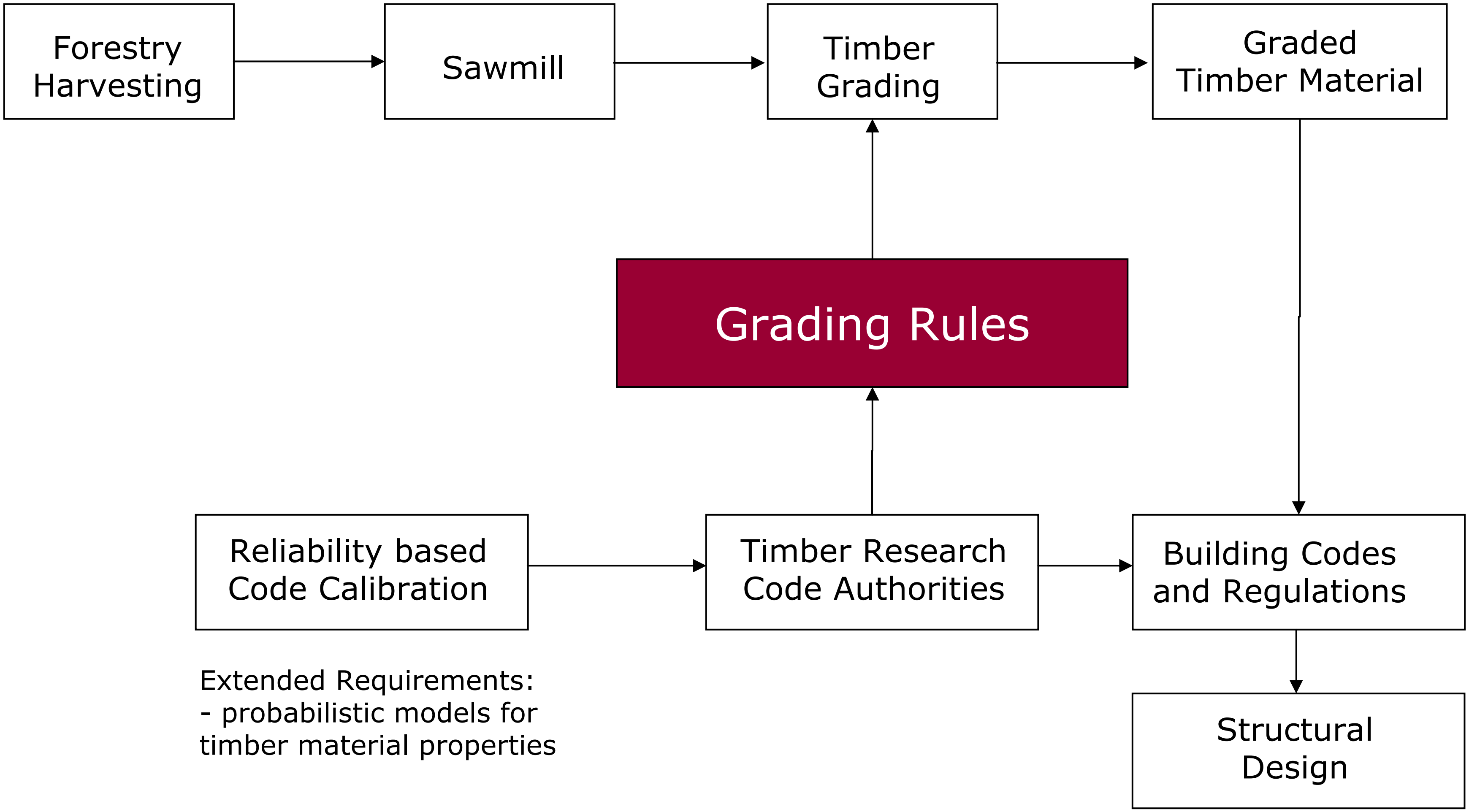
  René Steiger, EMPA
  Markus Deublein, PhD ETH/EMPA

introduction



Extended Requirements:
- probabilistic models for timber material properties

Derived Requirements:
- sufficient strength
- sufficient stiffness
- ...

outline

- Control method given in EN14081
- Alternative approach:
  Probabilistic modeling of timber material properties
- Conclusions

EN14081

- EN 14081, part 1: “General requirements” … (visual strength grading)
- EN 14081, part 2: “Machine grading – additional requirements for initial type testing.”
- EN 14081, part 3: “Machine grading – additional requirements for factory production control.”
- EN 14081, part 4: “Machine grading – grading machine settings for machine controlled systems.”

1. Output control: Continuous control by testing the grading machines‵ output.

2. Machine control: Extensive calibration process prior to the operation phase of the grading machine.

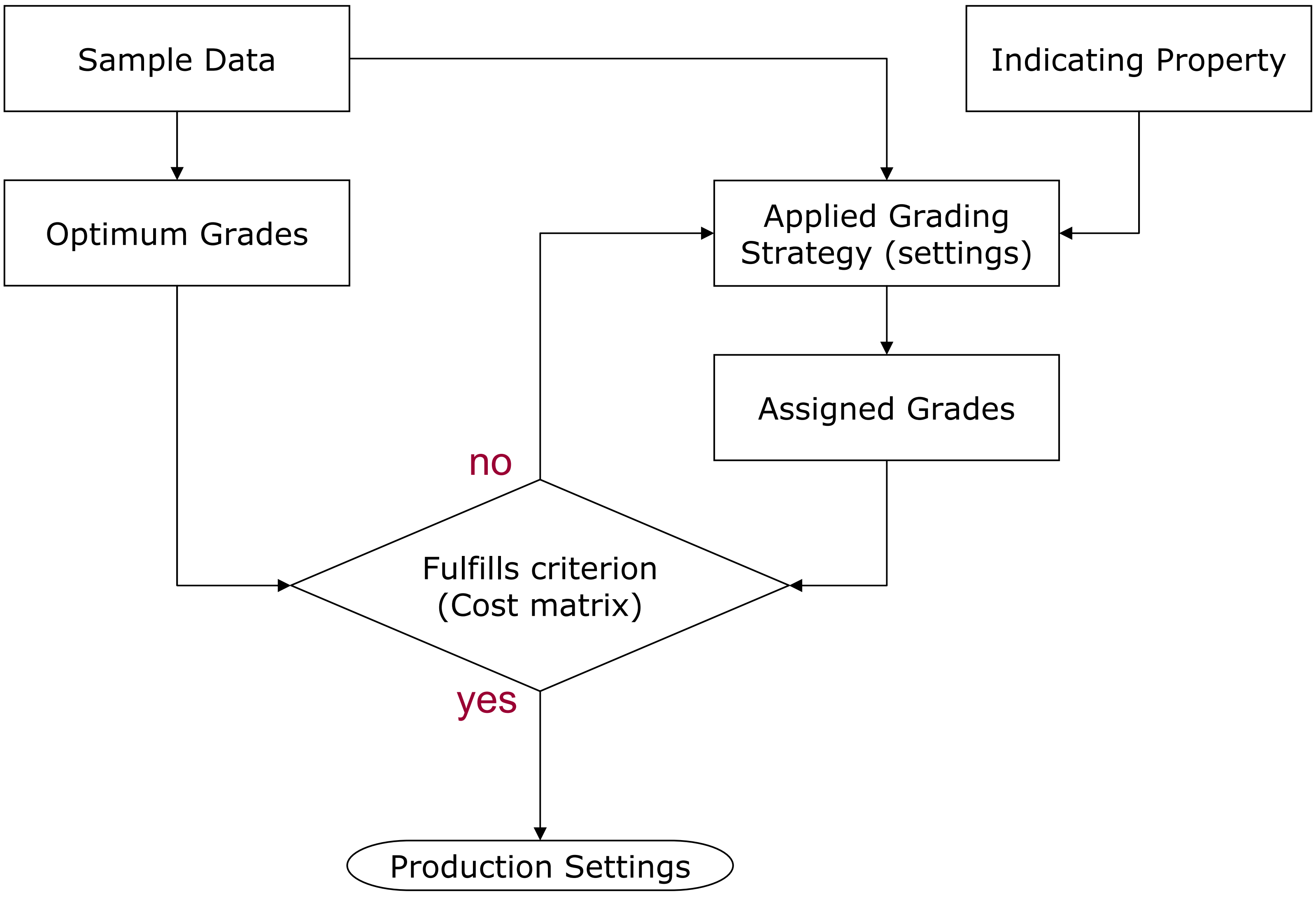
Both systems require a visual override inspection to cater for strength-reducing characteristics that are not automatically sensed by the machine.

EN14081 – machine control

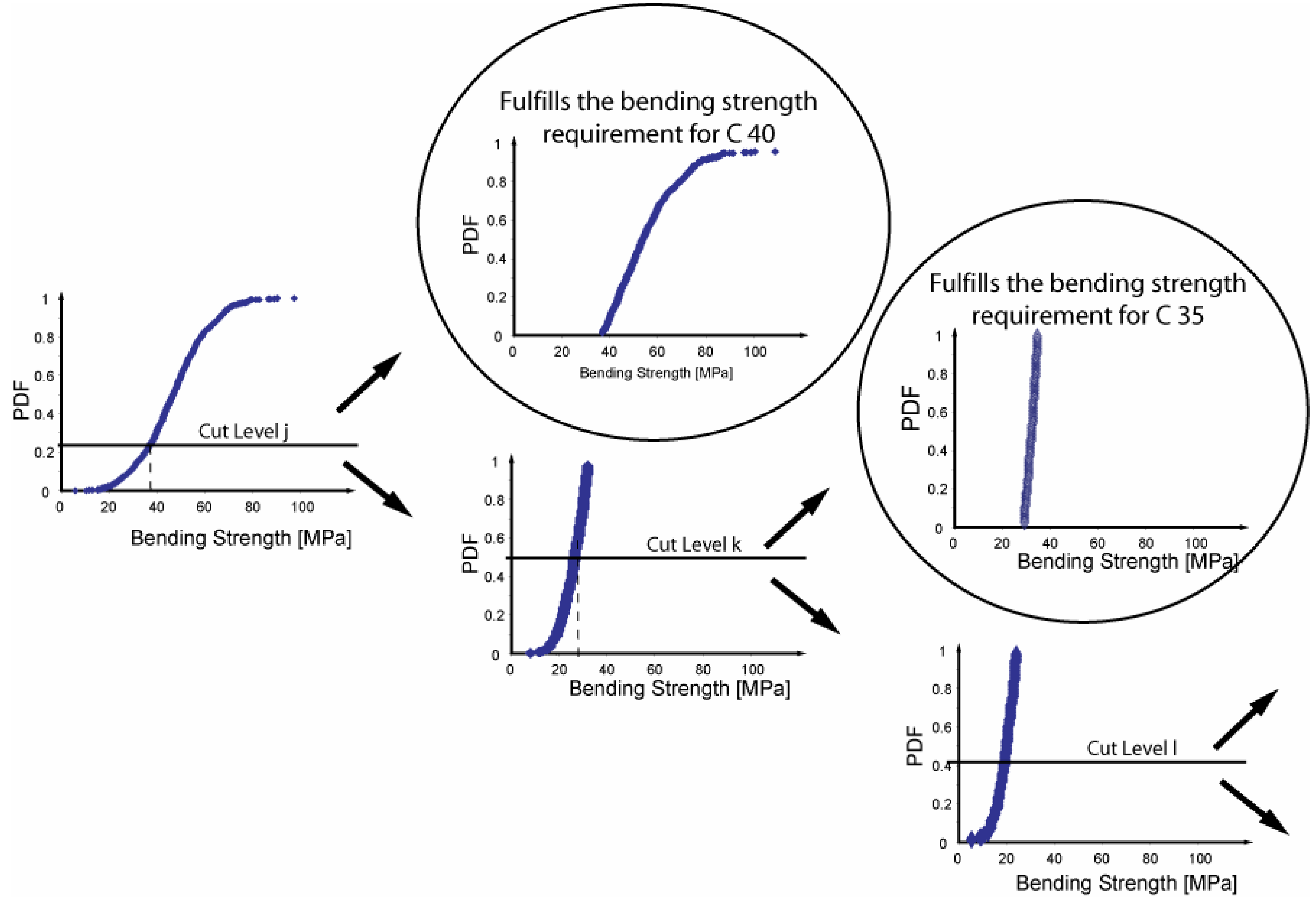
Related and important standards

- **EN338**: “Structural timber – Strength classes”
- **EN384**: “Structural timber – Determination of characteristic values of mechanical properties and density”
- **EN408**: “Timber structures – Structural timber and glued laminated timber – Determination of some physical and mechanical properties”

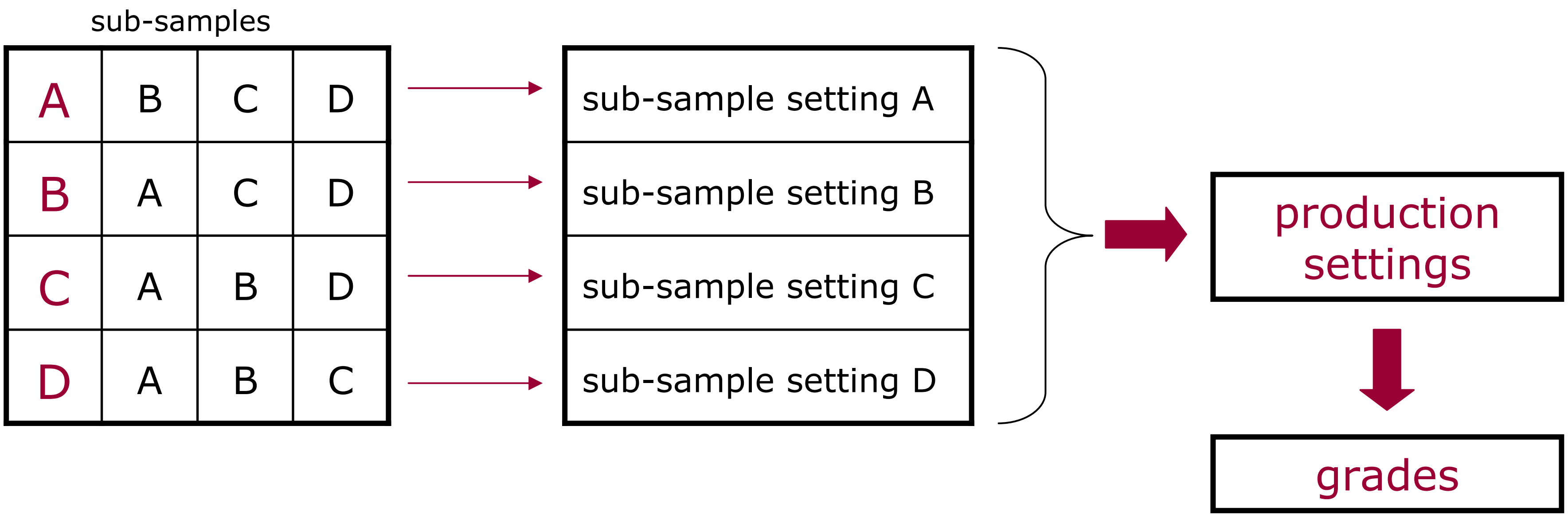
Assessment of production settings



Optimum grade



Assigned grade



- Settings shall be determined by considering all other sub-samples.
- Mean value of the sub-sample settings for calculation of production settings.
- Production settings for grading each piece into defined strength class.

Size-Matrix

Optimum grade	Assigned grade				
	C35	**C27**	**C22**	**reject**	
C35	207	32	16	2	**257**
C27	10	168	12	1	**191**
C22	4	13	84	2	**103**
reject	0	2	2	24	**28**
	221	**215**	**114**	**29**	**579**

EN14081 – machine control

Costs for wrongly upgraded specimen:

$$\text{Cost (upgrading)} = 10*(\beta_{target} - \beta)$$

Costs for wrongly downgraded specimen:

$$\text{Cost (downgrading)} = 10 * \sqrt[3]{\frac{MOE_{m,opt}}{MOE_{m,ass}}} - 1$$

Elementary cost matrix given in EN14081

Optimum grade	Assigned grade											
	C50	C45	C40	C35	C30	C27	C24	C22	C20	C18	C16	C14
C50	0,0	0,22	0,45	0,72	1,01	1,16	1,33	1,69	1,90	2,11	2,60	3,17
C45	0,37	0,0	0,23	0,49	0,77	0,92	1,09	1,45	1,64	1,85	2,33	2,89
C40	0,83	0,42	0,0	0,25	0,53	0,68	0,84	1,19	1,38	1,59	2,05	2,60
C35	1,43	0,95	0,48	0,0	0,27	0,42	0,57	0,91	1,10	1,30	1,76	2,29
C30	2,22	1,67	1,11	0,56	0,0	0,14	0,29	0,63	0,81	1,01	1,45	1,97
C27	2,84	2,22	1,60	0,99	0,37	0,0	0,15	0,48	0,66	0,85	1,29	1,80
C24	3,61	2,92	2,22	1,53	0,83	0,42	0,0	0,32	0,50	0,69	1,12	1,63
C22	4,24	3,48	2,73	1,97	1,21	0,76	0,30	0,0	0,17	0,36	0,77	1,26
C20	5,00	4,17	3,33	2,50	1,67	1,17	0,67	0,33	0,0	0,18	0,59	1,07
C18	5,93	5,00	4,07	3,15	2,22	1,67	1,11	0,74	0,37	0,0	0,40	0,87
C16	7,08	6,04	5,00	3,96	2,92	2,29	1,67	1,25	0,83	0,42	0,0	0,46
C14	8,57	7,38	6,19	5,00	3,81	3,10	2,38	1,90	1,43	0,95	0,48	0,0

EN14081 – machine control

Size-Matrix

Optimum grade	Assigned grade				
	C35	**C27**	**C22**	**reject**	
C35	207	32	16	2	**257**
C27	10	168	12	1	**191**
C22	4	13	84	2	**103**
reject	0	2	2	24	**28**
	221	**215**	**114**	**29**	**579**

Global Cost-Matrix

$$global = \frac{elementary * size}{\sum size}$$

Factor from the elementary cost matrix: 0.76

Optimum grade	Assigned grade			
	C35	**C27**	**C22**	**reject**
C35	0.0	0.06	0.13	0.20
C27	0.04	0.0	0.05	0.08
C22	0.04	0.05	0.0	0.13
reject	0.0	0.04	0.05	0.0

Cost criterion: wrongly upgraded values ≤ 0.2!

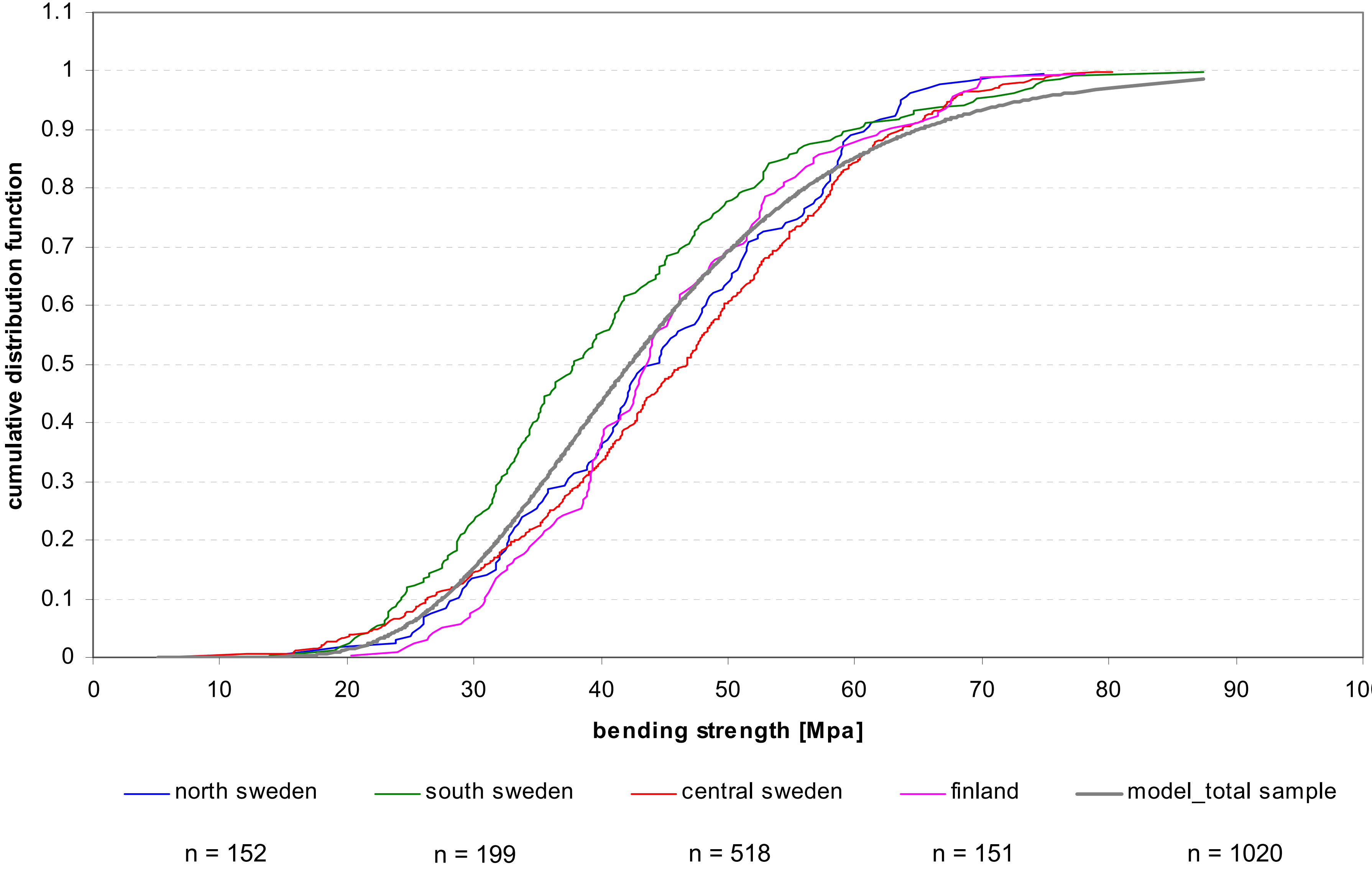
data set

- Sample size:
  1020 specimen;
- Species:
  Spruce
- Origins:
  North-, South- & Central-Sweden
  Finland
- Cross Sections [mm]:
  45 x 70
  45 x 145
  43 x 170
  45 x 190

- Device & measured Indicator:
  Frequency-Device (Indicating Property)
- Assessed Properties:
  - Bending Strength
  - Bending Young's Modulus
  - Density
  - Moisture Content

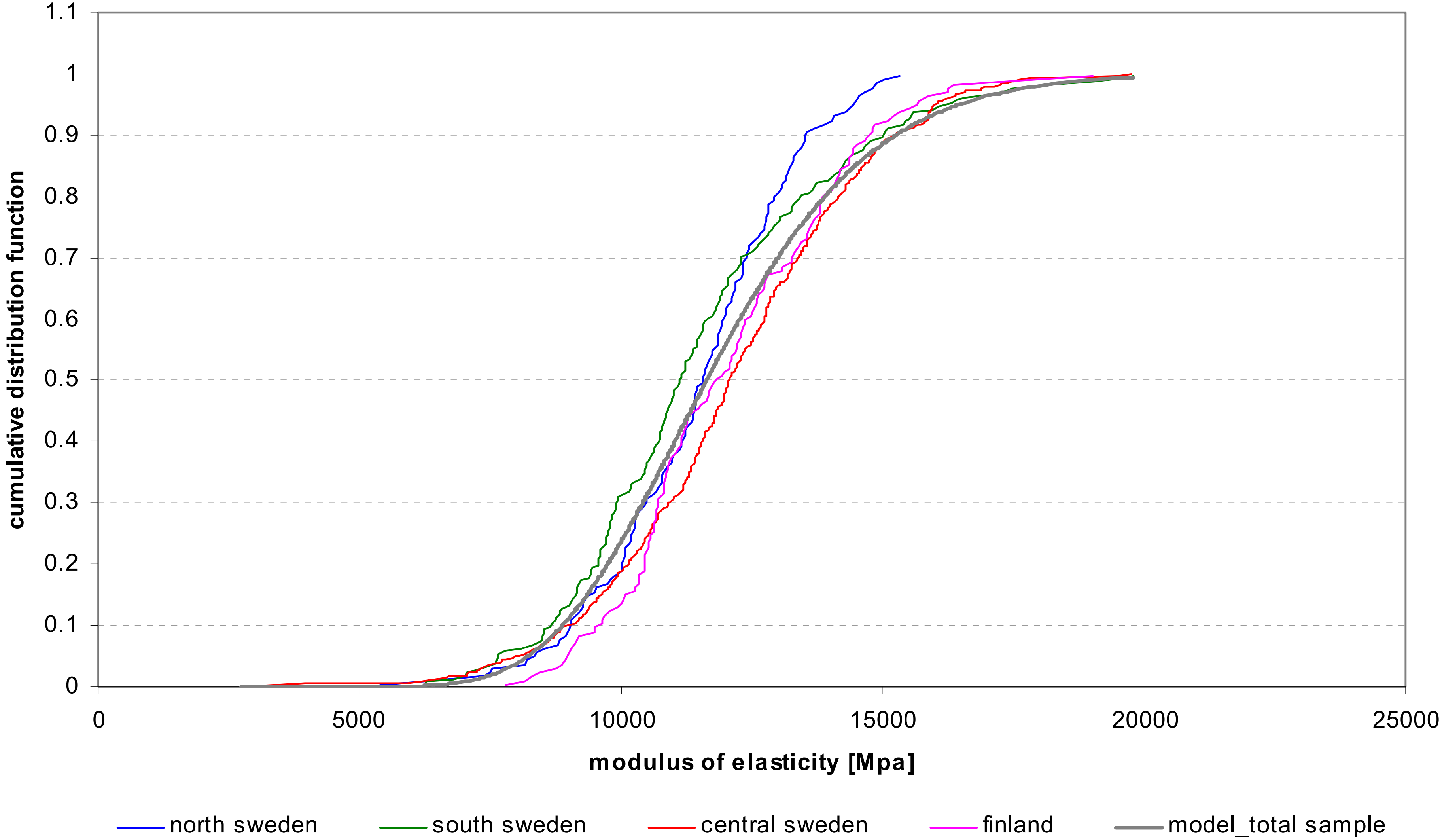
example - material properties

Bending strength



example - material properties

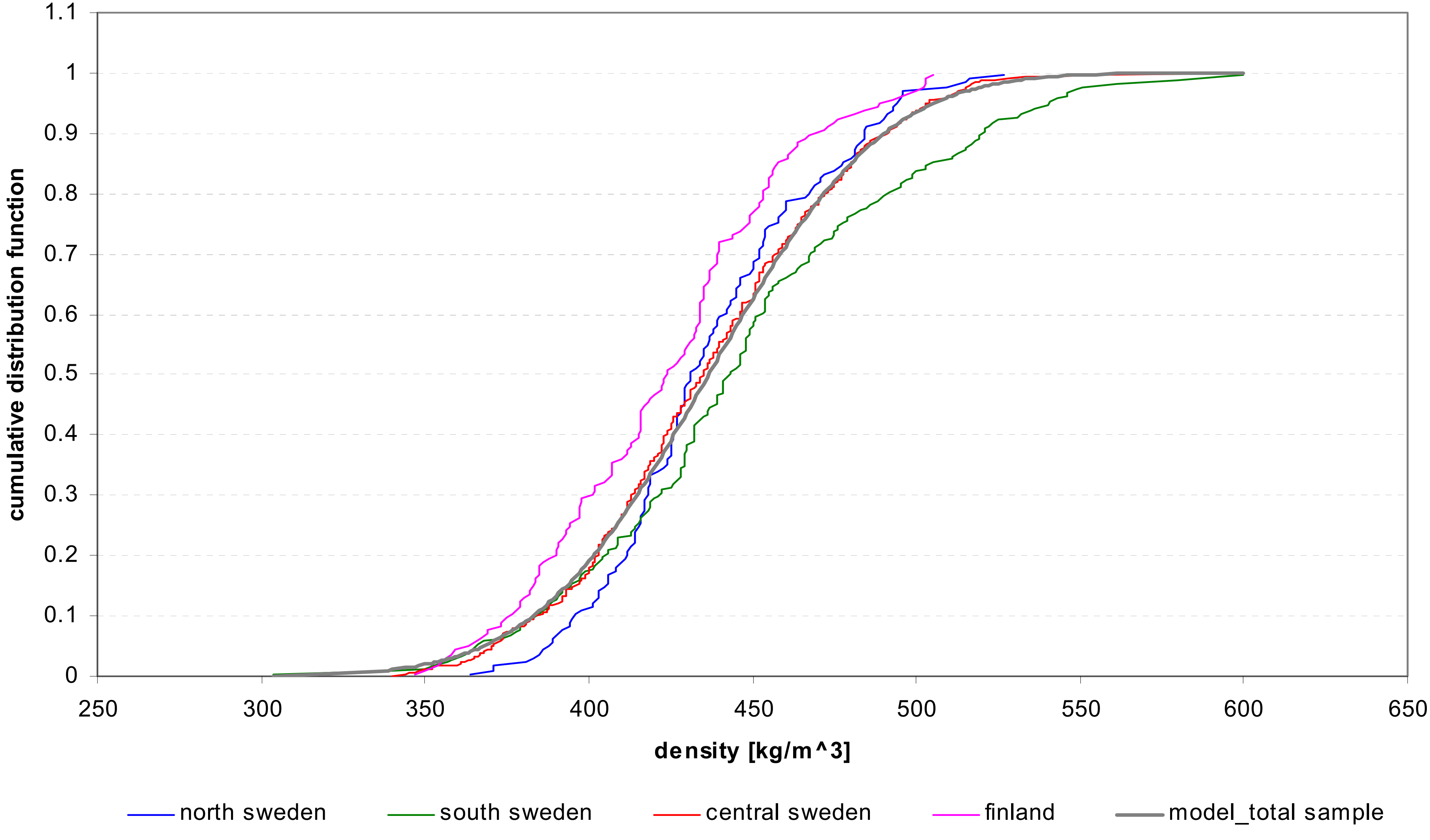
Modulus of elasticity



n = 152 n = 199 n = 518 n = 151 n = 1020

example - material properties

Density



n = 152 | n = 199 | n = 518 | n = 151 | n = 1020

Production settings and characteristic values

Characteristic values given in EN338

	Bending strength	Modulus of elasticity	Density
C30	30	12.000	380
C24	24	11.000	350
C14	14	7000	290

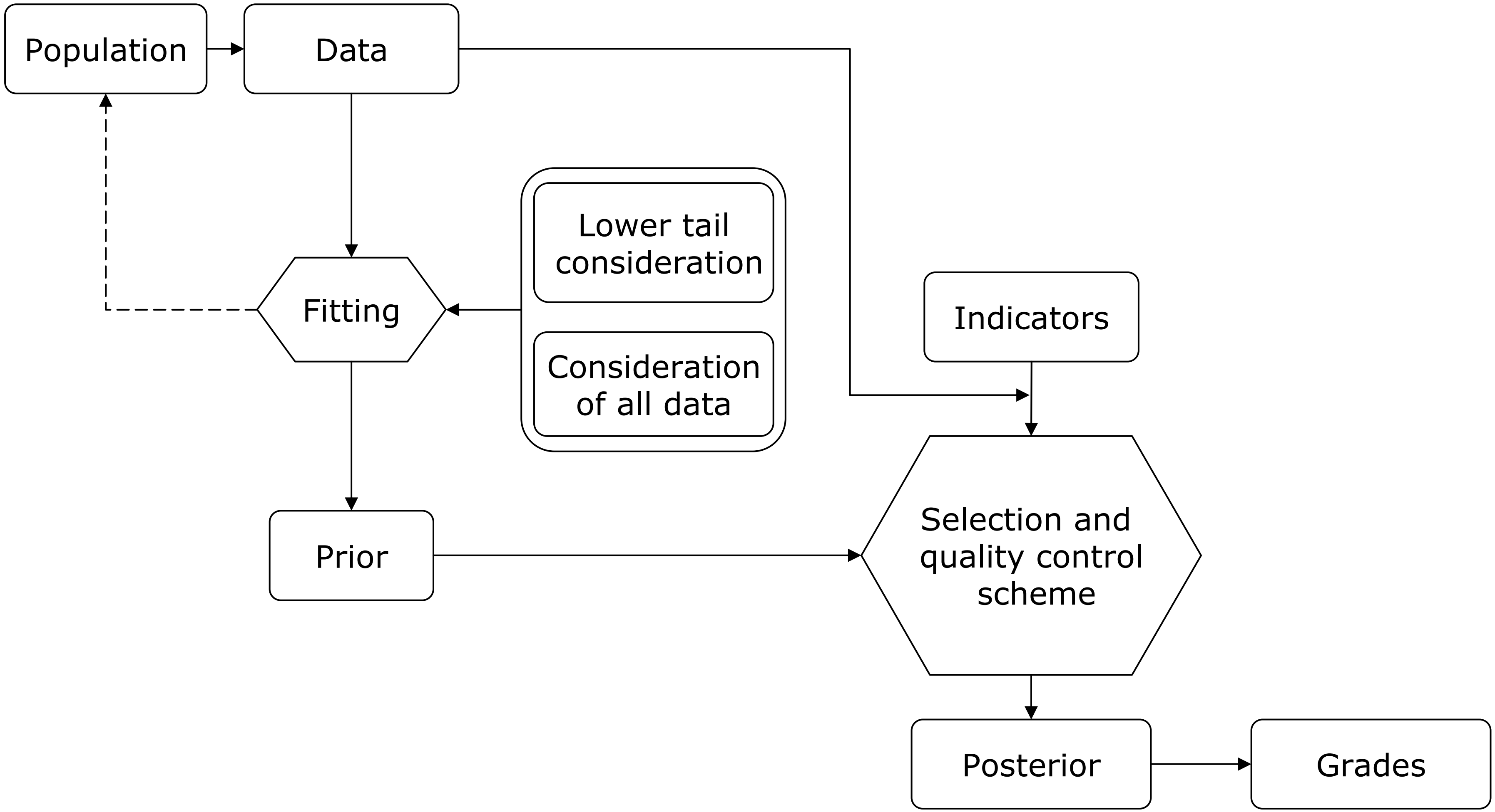
Characteristic values of the grades according to EN14081 (n=1020)

	IP	yield	strength	MOE	density
C30	≥ 7000	475	31.8	14775	**380**
C24	< 7000 ≥ 6400	295	26.3	11948	369
C14	< 6400 ≥ 4300	249	17.8	9873	354
reject	<4300	1	12.2*	6375*	367*

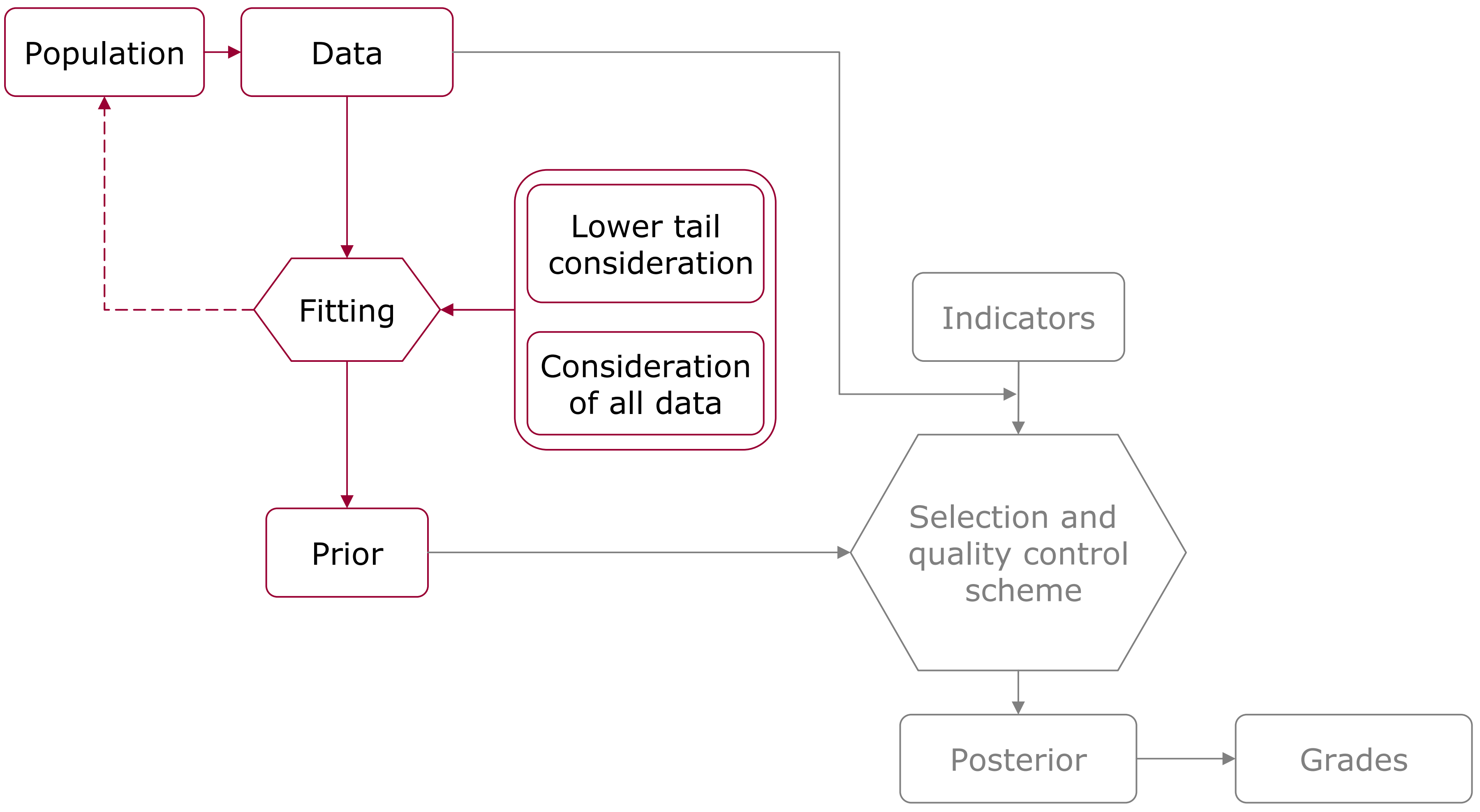
*=minimum value

- Control method given in EN14081
- Alternative approach:
  Probabilistic modeling of timber material properties
- Conclusions

probabilistic modeling - concept

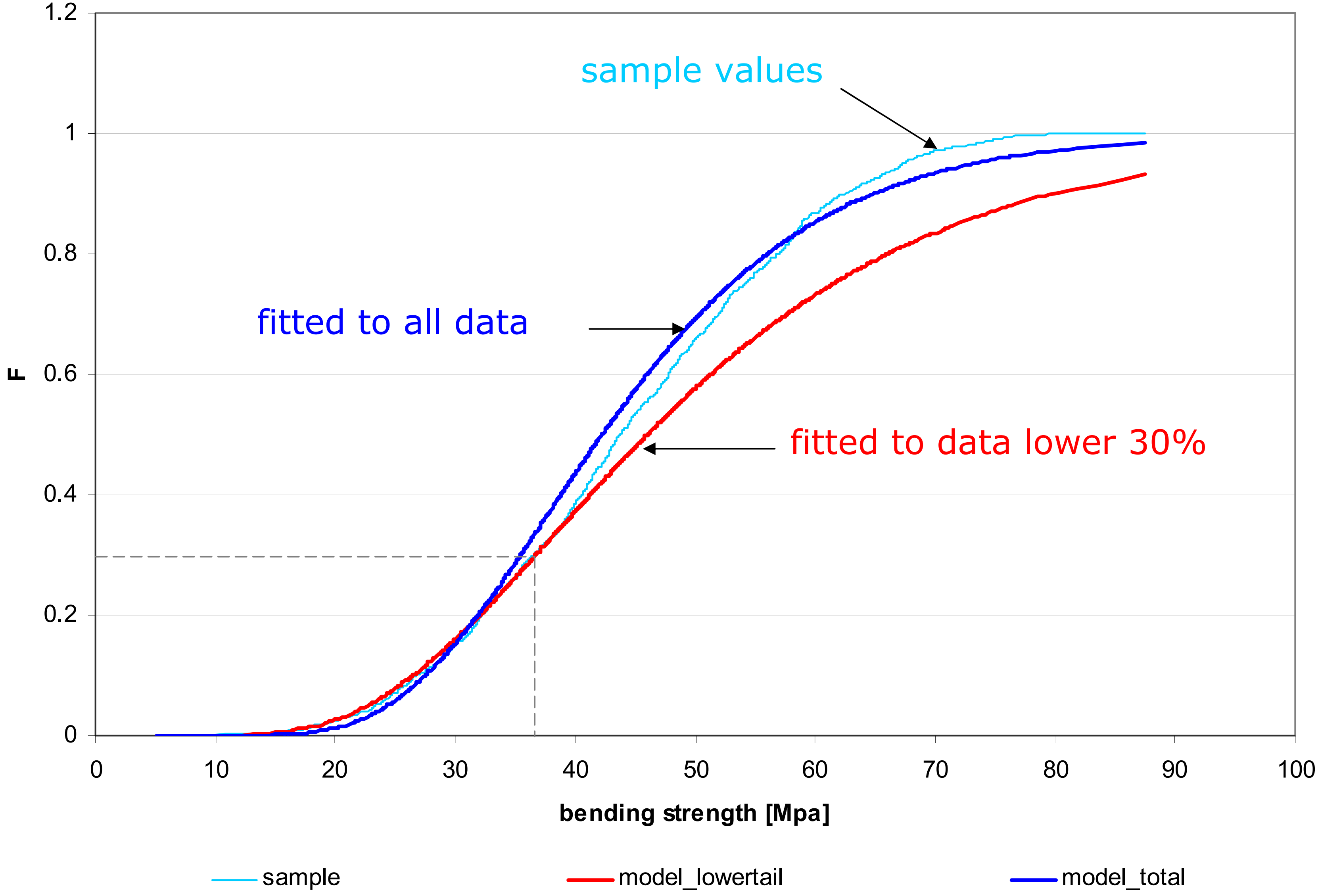


probabilistic modeling



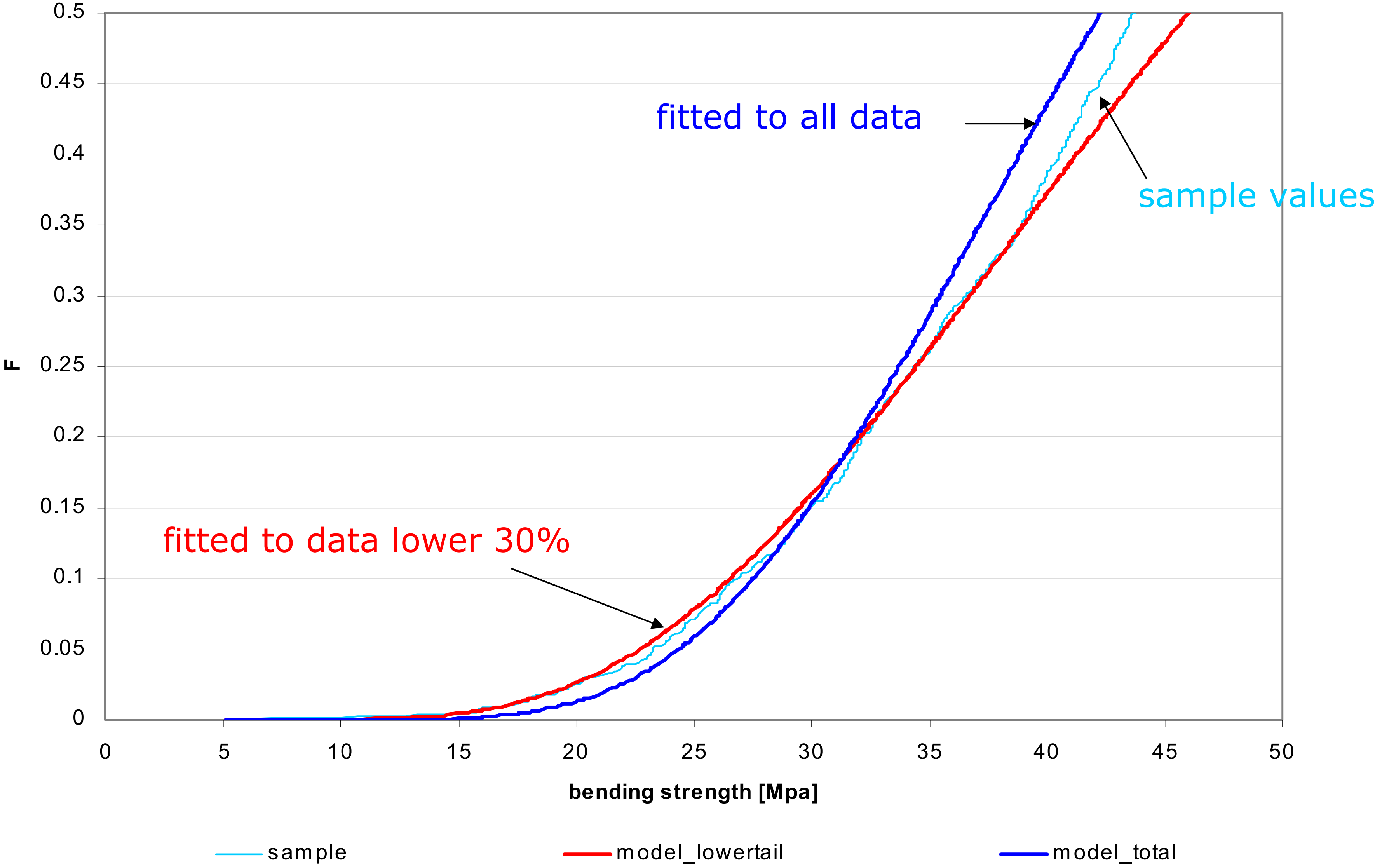
example lower tail fitting

Lower tail fitting

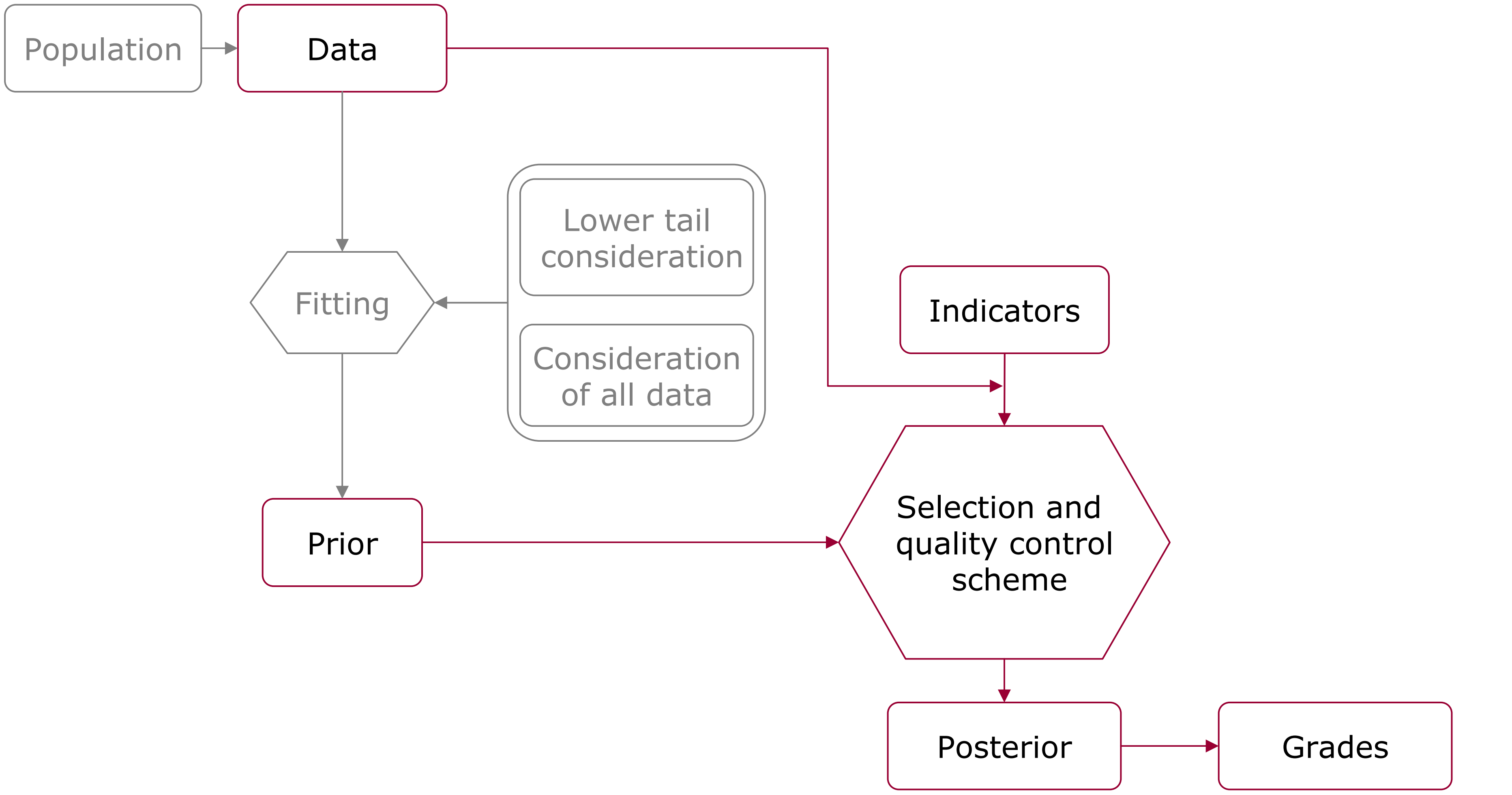


example lower tail fitting

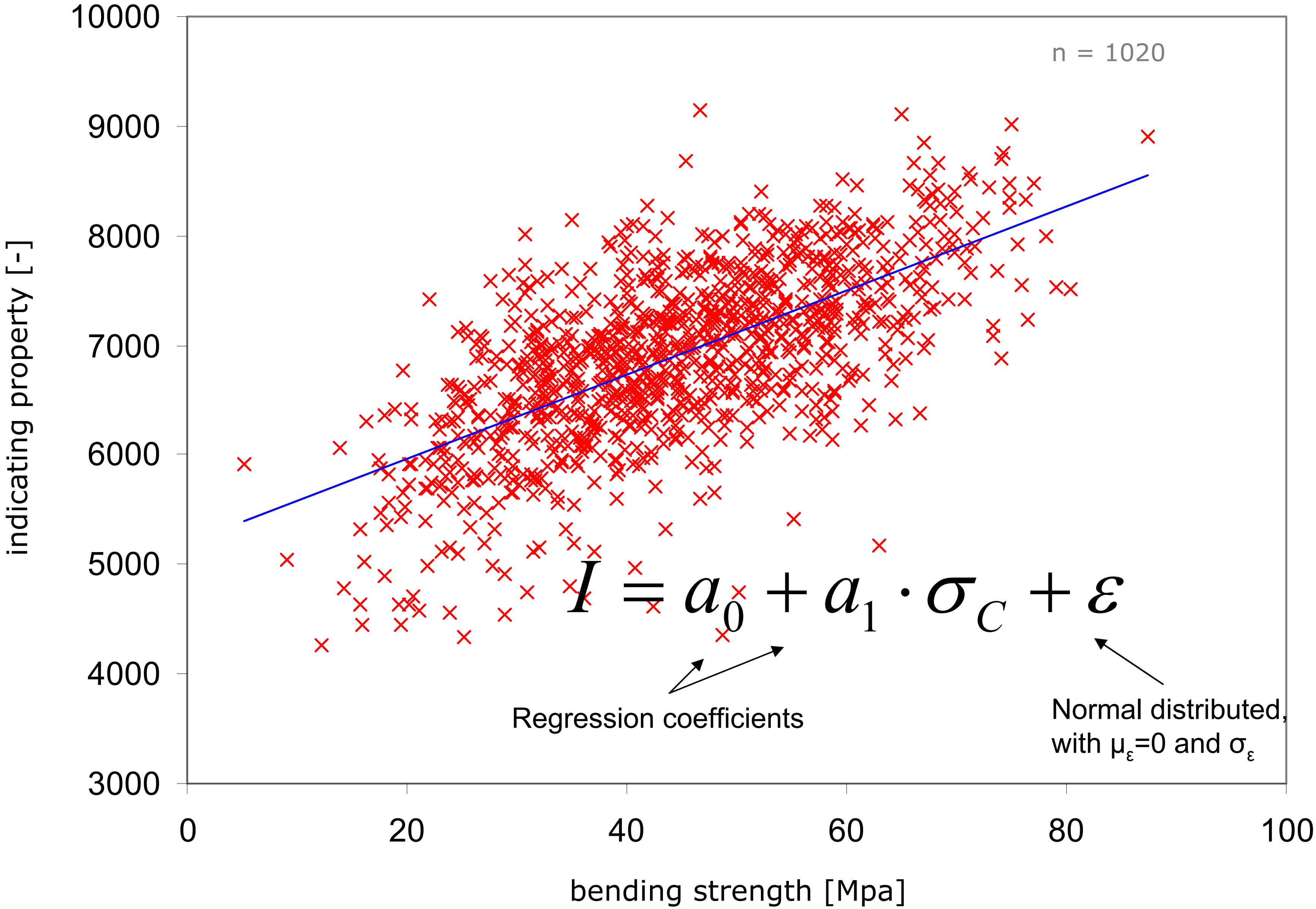
Lower tail fitting – larger scale



probabilistic modeling

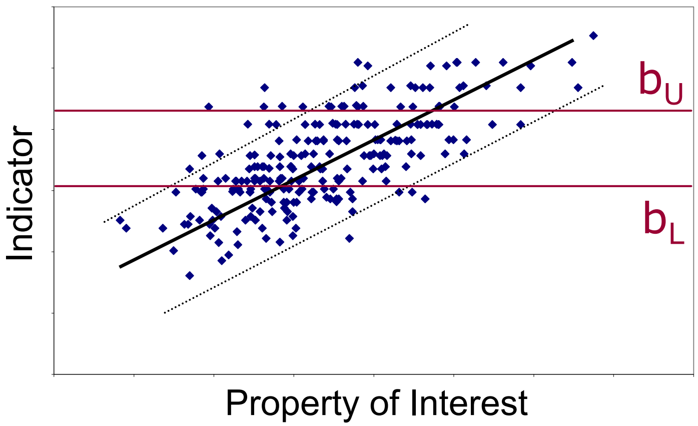


probabilistic modeling – regression analysis



$$I = a_0 + a_1 \cdot \sigma_C + \varepsilon$$

probabilistic modeling – probability of acceptance



An acceptance criteria may be formulated in form of

$$A_C = \{ b_L \leq I \leq b_U \}$$

where b_L and b_U are lower and upper bounds for the Indicator of a particular grade.

With the information from the regression analysis we assess the probability of acceptance $P(A_C|\sigma_C)$ by

$$P(A_C | \sigma_C) = P(b_L \leq a_0 + a_1 \cdot \sigma_C + \varepsilon \leq b_U)$$

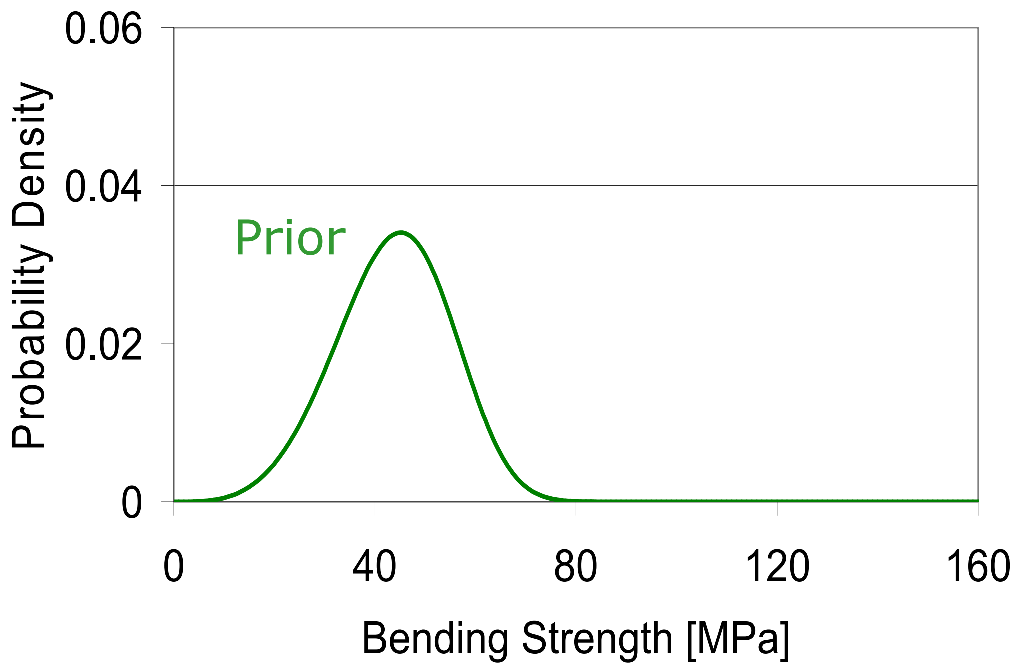
$$f''_{\sigma_C}(\sigma_C | A_C) = \frac{1}{c} f'_{\sigma_C}(\sigma_C) \cdot P(A_C | \sigma_C)$$

Posterior distribution function with application of the Bayes rule.

probabilistic modeling – Bayes rule

Prior

$$f''_{\sigma_C}(\sigma_C | A_C) = \frac{1}{c} f'_{\sigma_C}(\sigma_C) \cdot P(A_C | \sigma_C)$$

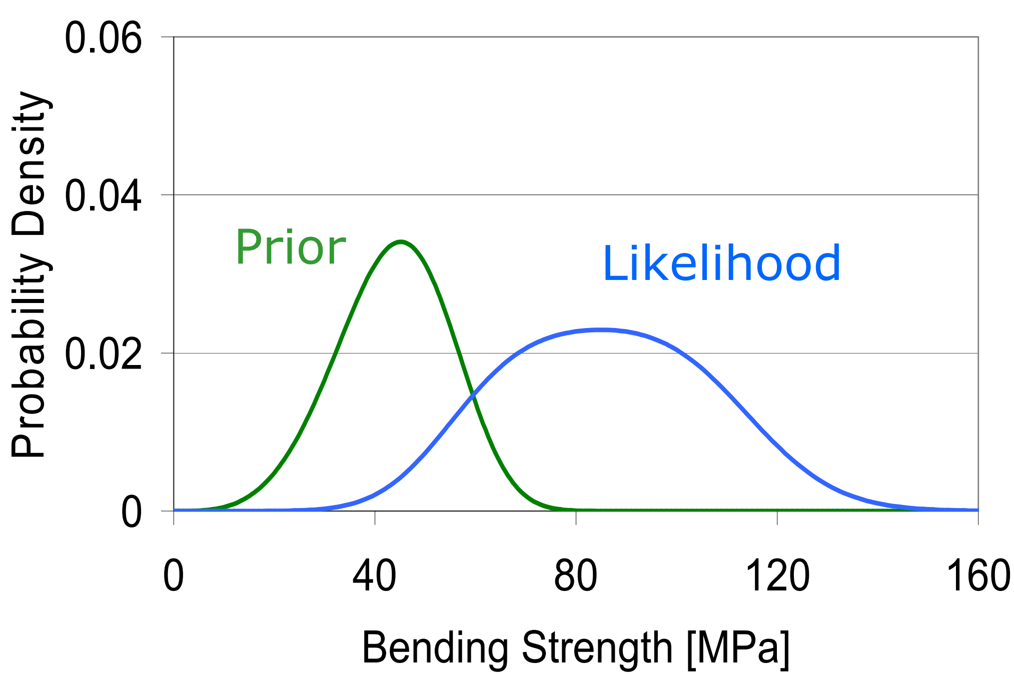


probabilistic modeling – Bayes rule

Prior

Likelihood

$$f''_{\sigma_C}(\sigma_C | A_C) = \frac{1}{c} f'_{\sigma_C}(\sigma_C) \cdot P(A_C | \sigma_C)$$



probabilistic modeling – Bayes rule

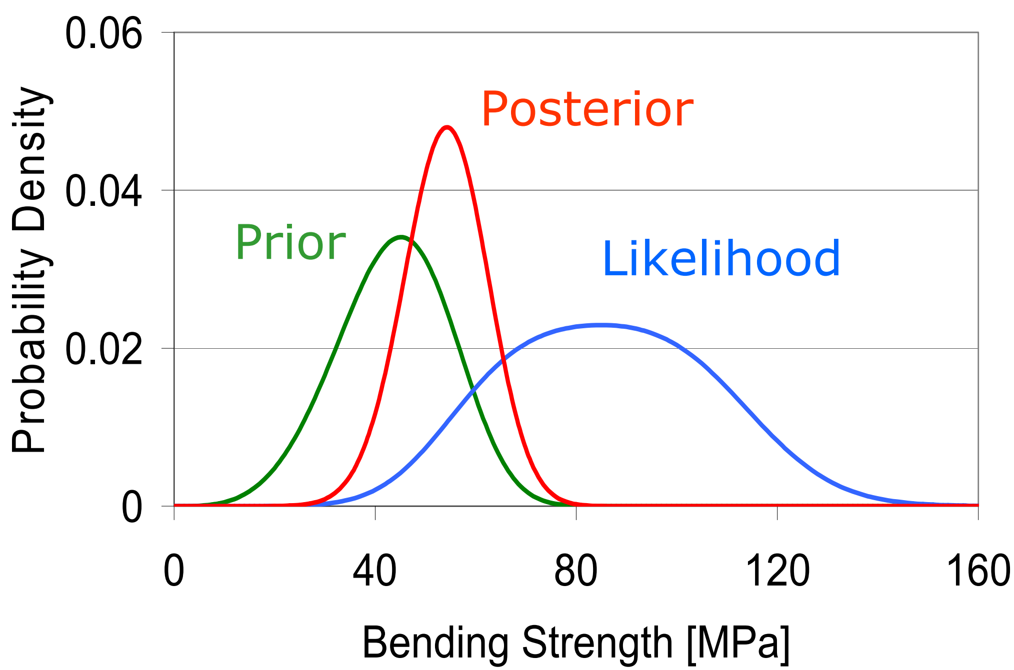
Posterior

Prior

Likelihood

$$f''_{\sigma_C}(\sigma_C | A_C) = \frac{1}{c} f'_{\sigma_C}(\sigma_C) \cdot P(A_C | \sigma_C)$$

Normalizing factor



results

Characteristic values of the grades according to EN14081 and the probabilistic model (total n=1020 specimens)

	IP		yield		strength		MOE		density	
	EN	model	EN	model	EN	model	EN	model	EN	model
C30	≥ 7000	≥ 7000	475	475	31.8	31.8	14775	14775	380	380
C24	< 7000 ≥ 6400	< 7000 ≥ 5950	295	429	26.3	24.5	11948	11577	369	366
C14	< 6400 ≥ 4300	< 5950 ≥ 4250	250	116	17.8	16.0	9873	8816	354	347
reject	<4300	<4250	1	0	12.2*	-	6375*	-	367*	-

*=minimum value

outline

- Control method given in EN14081
- Alternative approach:
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Summary

- The probabilistic approach does not only concentrate on the test sample but rather allows for a model extrapolation to the whole population.
- It is a central requirement that timber material properties can be probabilistically assessed.
- The grading procedure has to be considered in probabilistic modeling.
- Current grading practice does not allow an explicit consideration of the grading procedure in probabilistic modeling.
- The probabilistic approach is more feasible and consistent.
- Uncertainties have not to be calculated afterwards (by cost-matrices) but are included in the model.
- Alternative and more straight forward methods exist and it should be discussed how future codes and regulations could be advanced.

Thank you!

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