Uncertainties in determination of fire resistance by experimental testing and by calculation

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From deterministic results…

- Fire resistance of building construction elements can be assessed by experimental testing or by calculation (including numerical simulation).

- To date, results are expressed in a *deterministic* way.

  → i.e. *a single number as if there was no uncertainty*

  → e.g.

  "Loadbearing capacity: 27 minutes"

  "Integrity: 65 minutes"

  "Insulation: 58 minutes"

… to probabilistic results

- Asking different partners to assess the fire resistance
  - of a given element of building construction
  - subjected to a given fire scenario

  → they will report different results.

- Variability in the results depicts an uncertainty on the results.

- More information is enclosed in a ***probabilistic*** reporting of the results.

  → i.e. *according to a probability distribution*

  → e.g.

  "Loadbearing capacity: 27 ± 4 minutes"

  "Integrity: 65 ± 13 minutes"

  "Insulation: 58 ± 10 minutes"

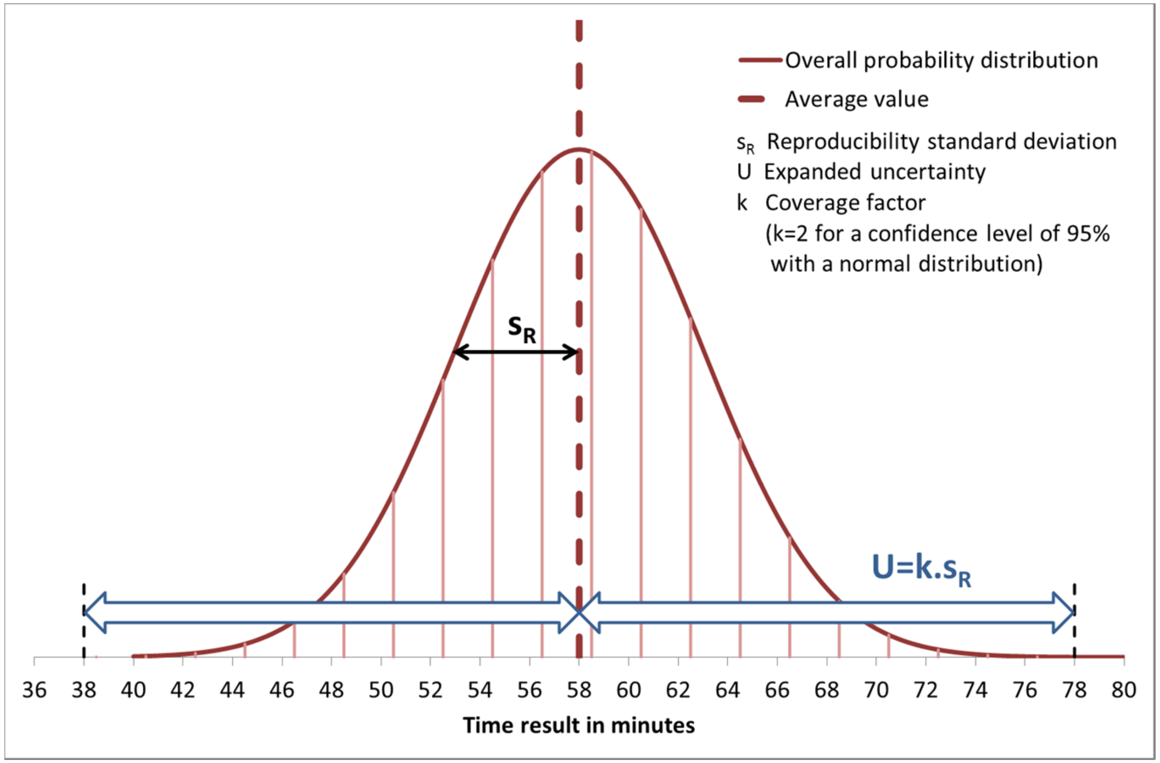
How to evaluate uncertainty?

- In fire resistance:
  - Analytical approach based on mathematical model → difficult in practice
  - Intercomparisons ("Round Robin") → appealing way to assess variability
- Round robins:
  - Testing community: each participating lab is requested to conduct several identical tests, on identical replicates of test specimen, under repeatability conditions.
  - Calculation community: each participant is requested to carry out calculations based on given input data.

Uncertainty evaluation

- Average value adopted as reference for discussion purpose (but no sense in defining a unique “true” value).
- The result is expressed as:

  “58 ± U minutes”



Uncertainty in testing

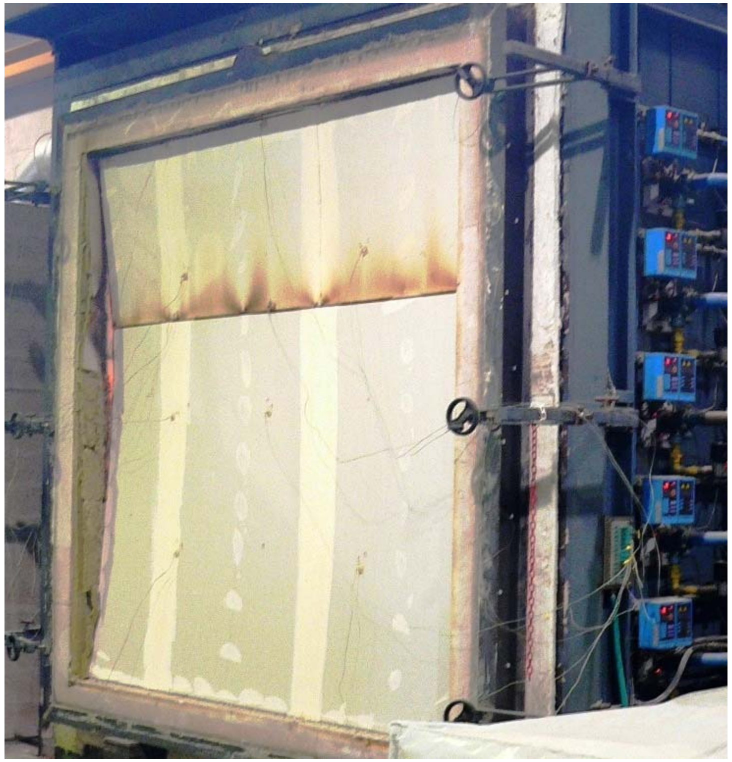
- Methods

  Set of standardised methods → Lab's practices are harmonized

- Results
  - Test methods describe fire performances with well defined criteria:
    - Loadbearing capacity (R)
    - Integrity (E)
    - Insulation (I)
  - Test result: time, in completed minutes, during which each performance is satisfied.

Uncertainty in testing

- Round Robin 1 in 2009
- EGOLF (European Group of Organisations for Fire Testing, Inspection and Certification)
- 32 participating labs x 2 specimens
- test specimen: non-loadbearing gypsum plasterboard partition



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Uncertainty in testing

- Round Robin 2 in 2014
- EGOLF
- 16 participating labs x 2 specimens
- test specimen:
  - steel beam
  - simply supported
  - 3-sides fire exposure
  - loaded in two points

Uncertainty in testing: results

		Round Robin with tests		
RR	**Performance**	**Mean**	**Standard deviation**	**Relative uncertainty at 95%**
Gypsum plasterboard partition	Integrity	65:09	6:28	20%
	Insulation	58:04	4:55	17%
Steel beam	Loadbearing capacity	31:37	1:47	11%

- Relative uncertainties on fire resistance test results (at 95% confidence interval) → uncertainty that may be expected between European laboratories
- Role of human factor

Uncertainty in calculation

- Methods

  There may be almost as many calculation methods, software used and assumptions as partners.

  → lack of harmonization

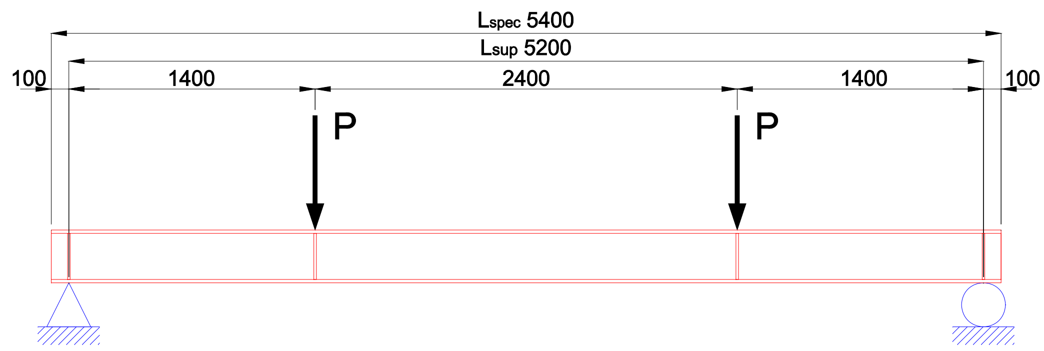
- Results

  Failure criteria?

  → lack of harmonization

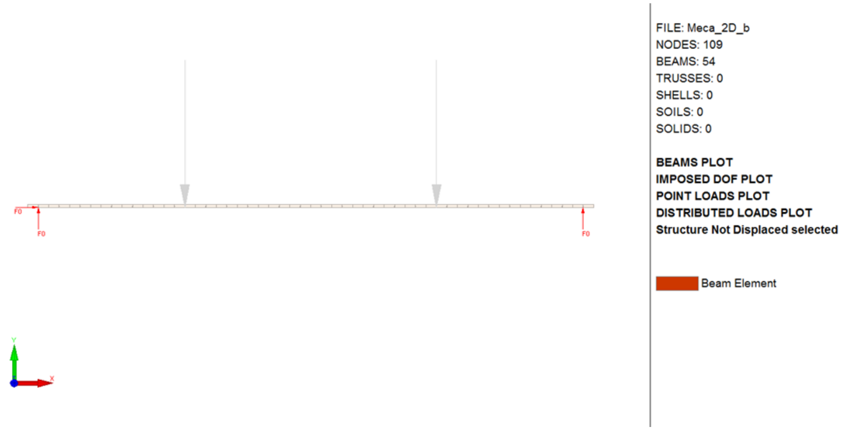
Uncertainty in calculation

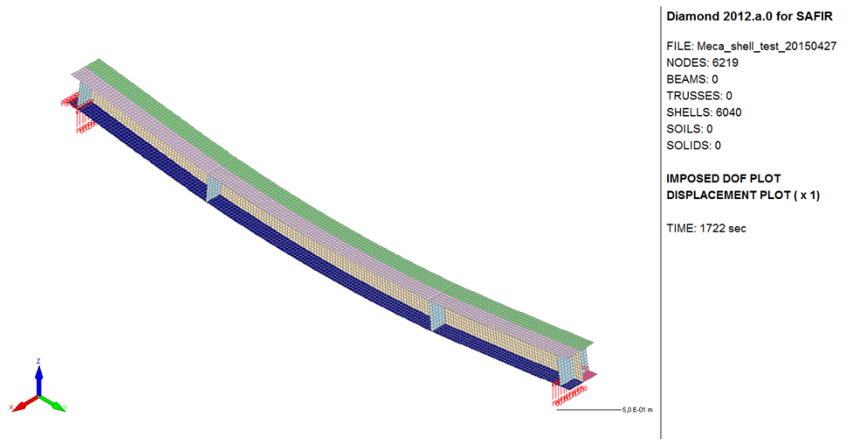
- Round Robin in 2015
- SP (Technical Research Institute of Sweden)
- 12 participants
- 19 calculations results
- Specimen:
  - steel beam
  - simply supported
  - 3-sides fire exposure
  - loaded in two points



Uncertainty in calculation: model ULg

- ULg used in-house software SAFIR®
- Considered 3 models:
  - Beam 2D
  - Beam 3D (captures torsion)
  - Shell (captures local buckling)
- Results:
  - Beam 2D and 3D identical
  - Shell: no local buckling, failure time differs by 30 sec (earlier)



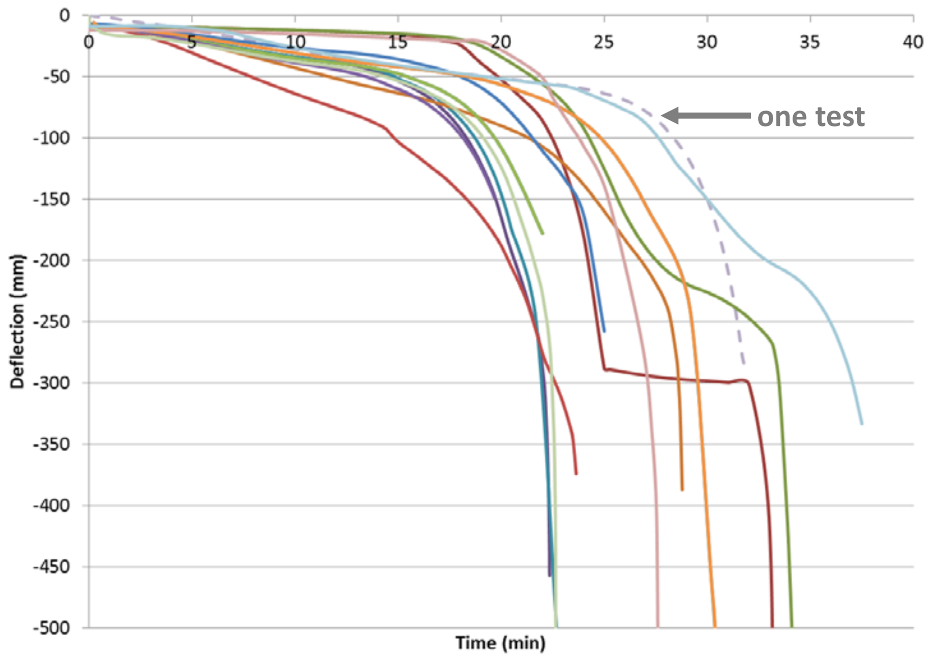


Uncertainty in calculation: results

- 1st stage « *a priori* »

Note:

- no two submissions used the same calculation approach, thermal exposure assumptions and mechanical modelling.
- finite element software, including using beam elements, shell elements and solid elements.



Calculated mid-span deflection histories

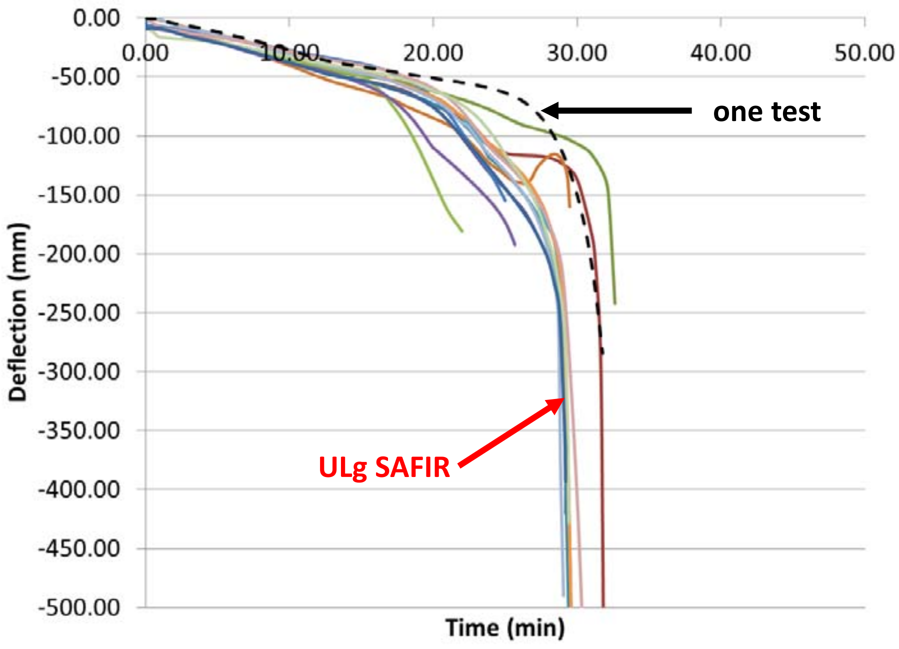
Uncertainty in calculation: results

- 2nd stage « a posteriori »

Additional information provided:

- Measured temperatures from the furnace plate thermometers and at the beam mid-span
  → Reduction of variability
- Measured steel yield strength
  → Better fit with the test result

Thermal analysis was source of significant variability in the results.



Calculated mid-span deflection histories

Uncertainty in calculation: results

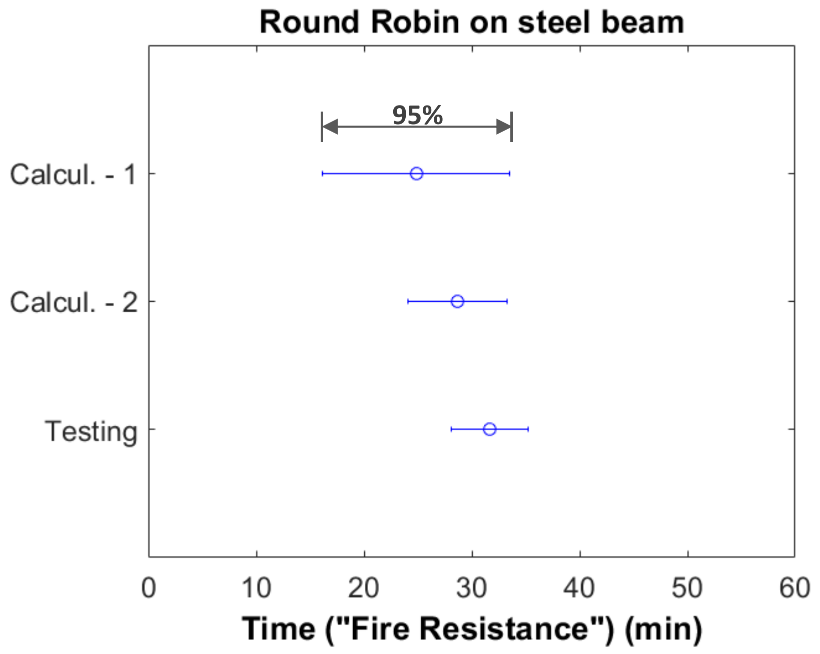
		Calculation RR					
		Stage 1			Stage 2		
RR	**Performance**	**Mean**	**St. Dev**	**Relative uncertainty at 95%**	**Mean**	**St. Dev**	**Relative uncertainty at 95%**
Steel beam	Loadbearing capacity	24:50	4:17	35%	28:41	2:14	16%

- Relative uncertainties on fire resistance calculation results (at 95% confidence interval)

→ uncertainty that may be expected between European “calculation” research teams

Discussion on this exercise

- Calculation was more conservative than testing.
- Calculation showed a larger variance than testing (testing has better standardization).
- Sources of variability:
  - Testing: operator
  - Calculation:
    - different softwares
    - different models
    - different users
    - lack of consensus for failure criteria
- Calculation stage 1 → 2: more detailed inputs reduce the variability in the results.



Conclusions

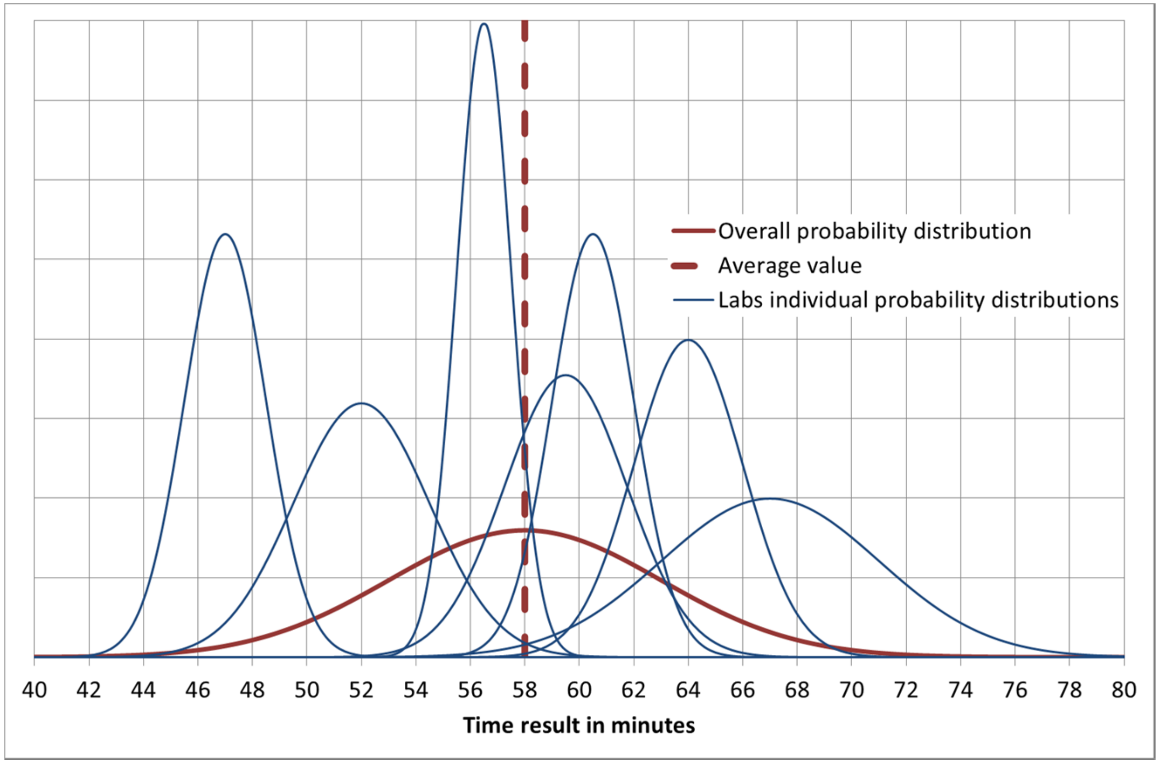
- Sources of variability
  - Aleatoric uncertainty: will always be present (not 2 specimens are rigorously identical).
  - Epistemic uncertainty: related to our models and methods.
- Need to improve methods and models to reduce the epistemic uncertainty
  - Testing: training the operators
  - Calculation: clear definition of failure
- Magnitude of the uncertainty
  - Not negligible
  - But limited compared to other unknowns e.g. fire scenario

Annexes

Uncertainty evaluation

In testing:

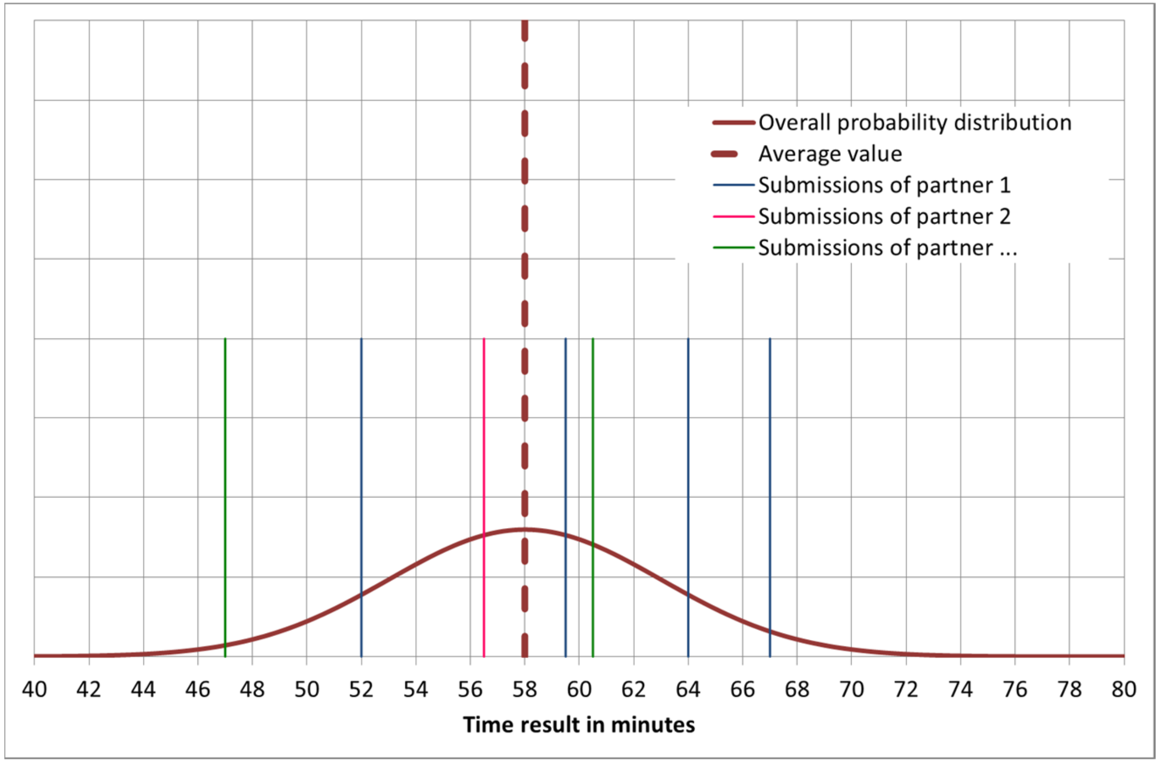
- One distribution of results by lab.
- One overall distribution.



Uncertainty evaluation

In calculation:

- One or several calculation method by partner.
- One result by calculation method and by partner.
- One overall distribution



Uncertainty evaluation