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Bridging the gap between model estimates and field measurements of probable maximum simultaneous demand - a Bayesian approach

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The Gaps between modelled and measured demands

Simultaneous maximum probable demands
(design flow rate)

Demand models
(analytical equation, probabilistic instantaneous distribution, time-series)

Hunter, Rybery, Courtney, Konon, Alitchkov, Goncalves, Murakawa, Wistort, Holmberg, Asano, Oliverira, Ilha, Pieterse-Quirigns, Blokker, Wong & Mui

Various standards & guidelines (BSEN, HASS, IOP, ASPE, …)

Different flow rate values

The choice of design value(s)
Balance between …

Certainty of services
Sustainability
Acceptability
…

Measurements
(Various buildings, researchers)

Measurement period?
Quality of the picked maximum value(s)?
Variant (climate, usage, occupancy, new equipment, facility arrangement, ...)

adequacy of model is questioned

Differences up to ~10 times or more!

Building type and location	Sample size n	Prior estimated design flow rate $q_{s,0}$ (Ls^{-1})	Measured (maximum) fraction α_m
Czech Republic			
Residential	12	1.09–3.79	0.483
		0.95–3.80	0.568
		0.80–2.34	0.684
		0.88–2.24	0.692
Netherlands			
Office	2	1.1–4.0	0.579–0.755
Hotel (cold)	2	1.5–1.8	0.437–0.567
Hotel (hot)	2	0.71–1.17	0.416–0.441
Nursing home	2	1.5–3.2	0.385–0.571
South Africa			
Residential	1	18.8	0.466
Japan			
Residential	29	2.9–65	0.522
Office	1	11.8	0.271
Restaurant	1	10.4	0.846

Difficulty regarding 'design flow rate'

no conclusive data to favor either model or measurement outcome

One may ask, "Which reference, model ones or field survey outcome, shall be the design criterion for installation?"

Our position

To make a judgmental decision based on the best information available

Estimate vs measurement Differences up to ~10 times or more!

Bayesian approach could help

Bayes' theorem (Reverend Thomas Bayes,1763)

Plato's Philosophy

'Fixed' Idea
(truth)

Metaphysics

Random
observation
(by chance)

Probability of
occurrence

Aristotle's Philosophy

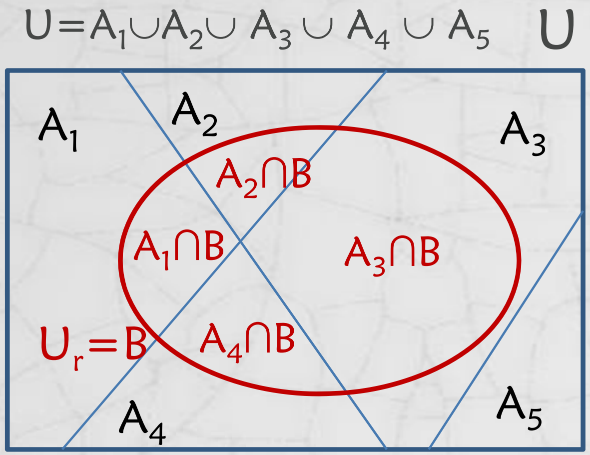
Belief
(Adjustable)

Observation
(truth)

Update of
belief

Bayesian approach: operation of the updating

Bayes' theorem (Reverend Thomas Bayes,1763)



- Events A_i partition the universe U and event B
- The reduced universe given event B has occurred, together with the events partitioning the universe
- $A_i \cap A_j = \phi$; i=1…; j=1…; $i \neq j$
- Then we say the set of events $B_1, \ldots B_n$ partitions the universe

- An unobservable event B will be partitioned into parts by the partition, and with the law of total probability, we have: $P(B)=\Sigma_{j=1\ldots n} P(B \cap A_j)$
- The probability of an event B is the sum of the probabilities of its disjoint parts. Using the multiplication rule, $P(B)=\Sigma_{j=1\ldots n} P(B|A_j)\, P(A_j)$
- The conditional probability, for i=1…n is found by dividing each joint probability by the probability of the event B, $P(A_i|B)= P(B \cap A_j) / P(B)$
- Using the multiplication rule to find the joint probability in the numerator and the law of total probability in the denominator,
- $P(A_i|B)= P(B|A_j)\, P(A_j) / \Sigma_{j=1\ldots n} P(B|A_j)\, P(A_j)$ ← Baye's theorem

Description of the Bayesian approaches

Data quality (variance)? Unknown!

$$\beta = \sqrt{\frac{\phi}{\phi_0}}$$

$$\beta = \beta\left(n_\infty, \varepsilon_\infty, \alpha\right)$$

Require to make decision: *n*, ε_∞

Prior data 0: existing belief

Posterior: revised belief (sample size dependent)

$$q_{d,1}^* \sim \theta_1 = \left(q_{d,0}^* + q_x^* \beta^{-2}\right)\left(1+\beta^{-2}\right)^{-1}$$

Difference α

Bayesian descriptions

$$p\left(q_{d,0}^* \mid q_x^*\right) = p\left(q_{d,0}^*\right) p\left(q_x^* \mid q_{d,0}^*\right)$$

Parametric distribution

$$\phi_1 = \left(\phi_0^{-1} + \phi^{-1}\right)^{-1}$$

$$\theta_1 = \phi_1 \left(\frac{\theta_0}{\phi_0} + \frac{q_x^*}{\phi}\right)$$

Target sample size n_∞

Acceptable estimate

Acceptable error ε_∞

Measured data: large difference limited samples

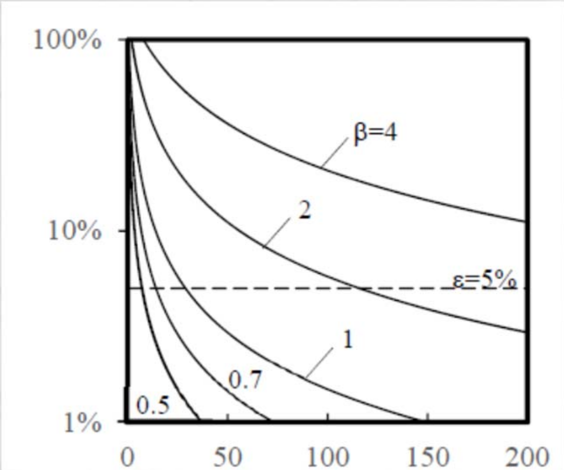
"Truth"

q

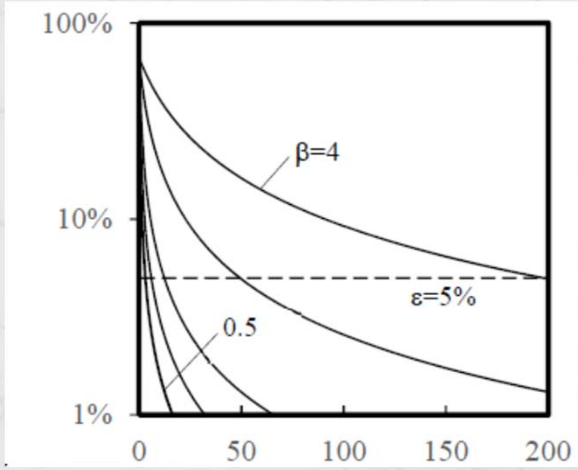
sample size

Example calculation of β for the problem domain

α=0.4



α=0.6



x-axis: Sample size *n*. y-axis: error ε (%).

Available: $q^*_{d,0}$, q^*_x

To find: α

$\beta = \beta(n_\infty, \varepsilon_\infty, \alpha)$

Use $\alpha, n_\infty, \varepsilon_\infty$ → To find β

An application example

Bayesian coefficient

Original Hunter's equation

Hunter fixture unit approach, U
Murakawa (1985) measurement data

$$q_{d,1}(U) = \alpha_n q_{d,0}(U)$$

New estimate

Procedure 1: Sample maximum and sample size

Table 1. Design flow rates of loading units (Murakawa 1985)

No.	Loading unit U	Hunter's estimated design flow rate q_d	Measured probable maximum flow rate q_x	α
1	90	2.9	1.2	0.4138
2	250	5.7	2.2	0.3772
3	500	8.5	4.2	0.4976
4	950	14.0	6.2	0.4450
5	1000	15.0	6.5	0.4333
6	1250	17.0	6.1	0.3588
7	2030	23.4	8.1	0.3462
8	2050	23.6	8.9	0.3771
9	2300	27.0	9.5	0.3519

maximum =0.4976

Graphical illustration

x-axis: Sample size n. y-axis: α.

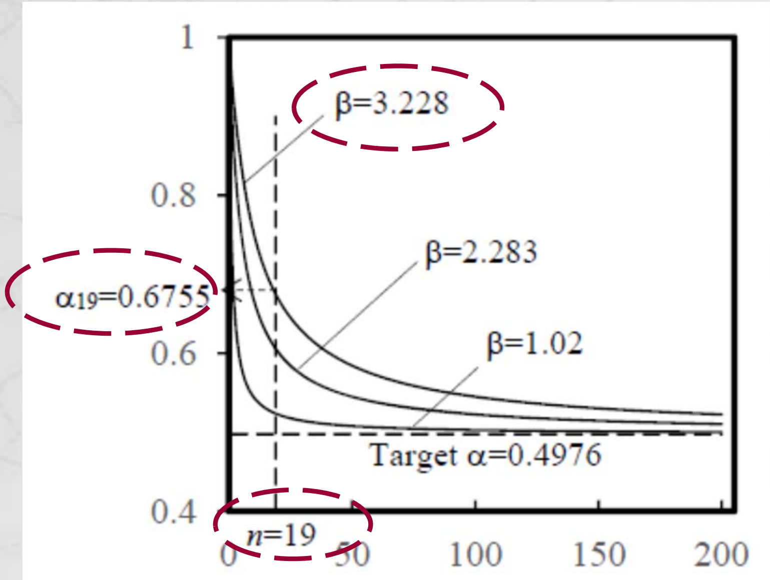


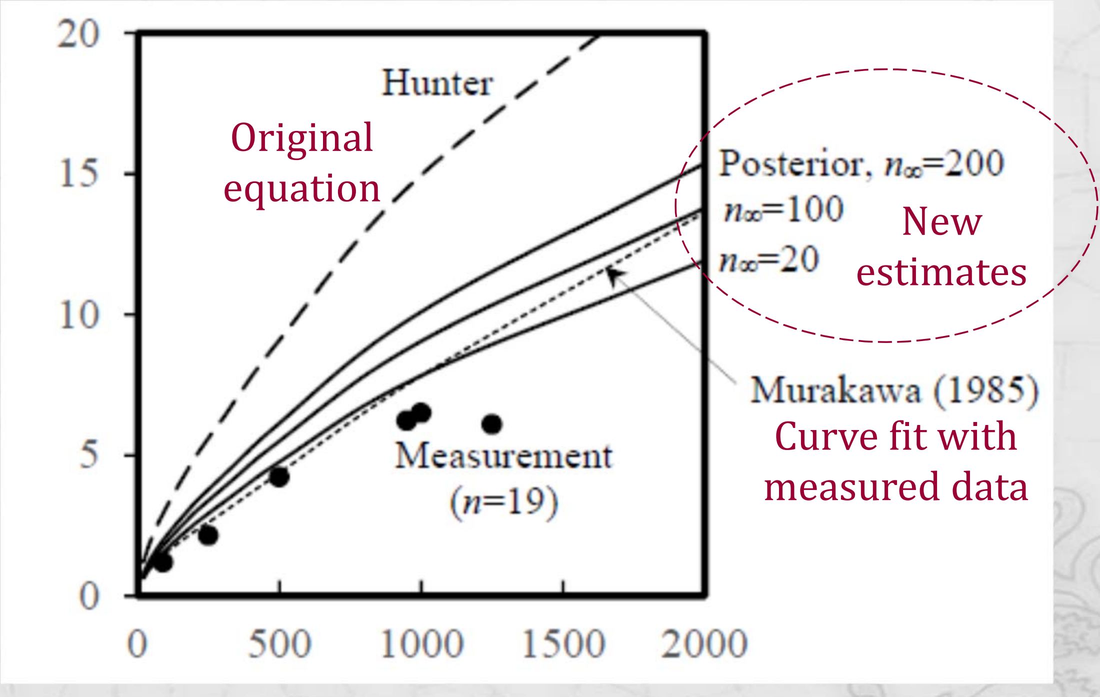
Illustration for: α=0.4976
target sample size: n_∞=20, 100 and 200
acceptable error ε=0.05

corresponding
β=1.02, 2.283, 3.228,
$\alpha_{n=19}$=0.5237, 0.6058, 0.6755

Bayesian coefficient

Graphical illustration

x-axis: Loading unit. y-axis: Design flow rate q_d (Ls^{-1})



Example from CIBW062

Bayesian coefficients

Existing model estimates

Building type and location	Sample size n	Prior estimated design flow rate $q_{s,0}$ (Ls^{-1})	Measured (maximum) fraction α_m	α_n (Reference design guide) n_∞=50	n_∞=100	n_∞=200
Czech Republic				CSN75-5455 (Czech)		
		1.09–3.79	0.483	0.571	0.633	0.715
				EN806-3 (British)		
		0.95–3.80	0.568	0.666	0.728	0.801
Residential	12			W3 (Swiss)		
		0.80–2.34	0.684	0.796	0.843	0.895
				DIN1988-300 (Germany)		
		0.88–2.24	0.692	0.799	0.850	0.901
Netherlands				Dutch guidelines		
Office	2	1.1–4.0	0.579–0.755	0.956	0.976	0.994
Hotel (cold)	2	1.5–1.8	0.437–0.567	0.844	0.904	0.946
Hotel (hot)	2	0.71–1.17	0.416–0.441	0.725	0.817	0.891
Nursing home	2	1.5–3.2	0.385–0.571	0.800	0.874	0.927
South Africa				W308 (Germany)		
Residential	1	18.8	0.466	0.837	0.904	0.947
Japan				Loading unit (Japan)		
Residential	29	2.9–65	0.522	0.565	0.602	0.695
Office	1	11.8	0.271	0.627	0.750	0.847
Restaurant	1	10.4	0.846	0.992	0.996	0.998

Remarks and Reflection (4Ps)

The use of Bayesian approach

- Philosophically consistent to a person who wants to make consistent and sound decisions in the face of uncertainty
- Prior probabilities can be from any existing demand models (codes, standards, guildlines)
    - minimal revision to all existing procedures: just apply a correction factor (Bayesian coefficient)
- Parameters are (sample size and acceptable error) physically meaningful
- Point to be noted: quality of measurement ‘peak’ available is non uniform; shall we have some measurement protocols?

Thank You

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