Automatic measured data validation applied on hydraulic and water quality parameters in sewer systems

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Research challenges

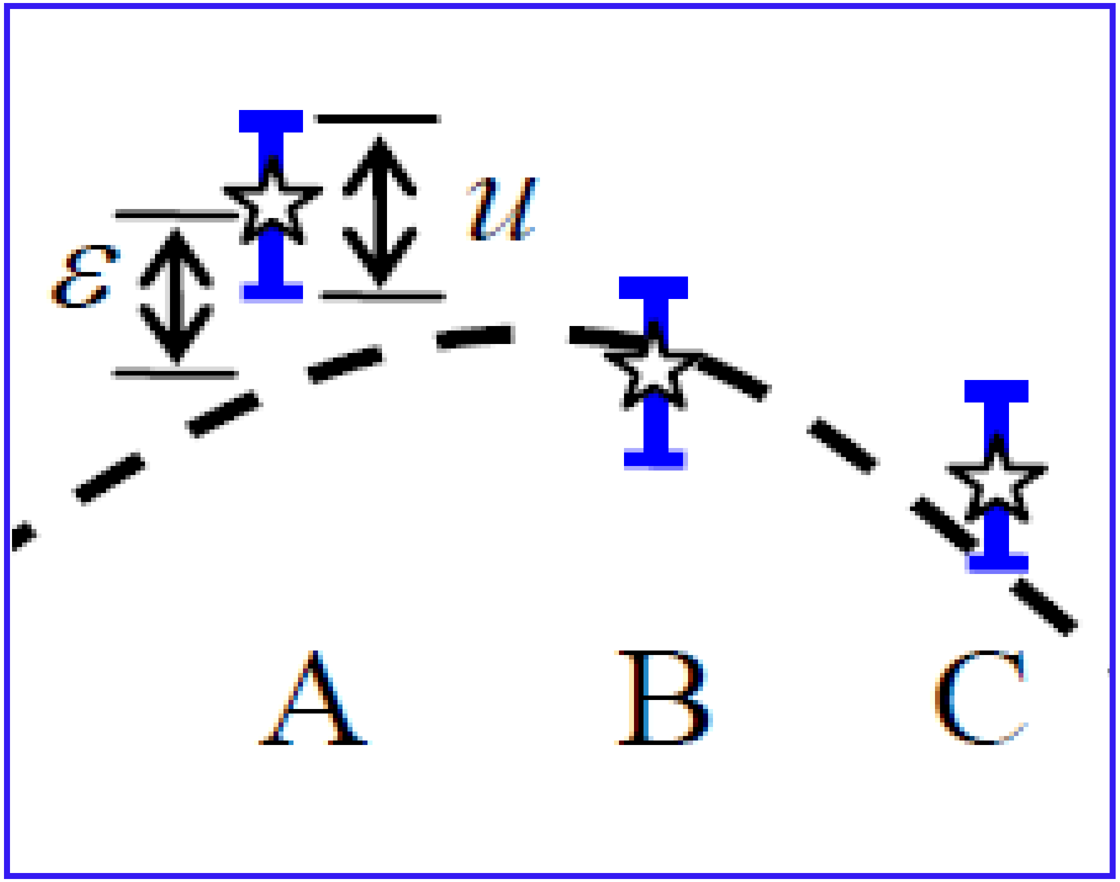
Challenge 1:
Large amount of data can not be validated traditionally

Challenge 2:
Data validation procedure have to be capable to use any kind of information available

Challenge 3:
Data validation procedure have to be independent on type or number of relations between data

Measured data values

- Exact value (------) – not available
- u - uncertainty
- ε - error



Measured data values

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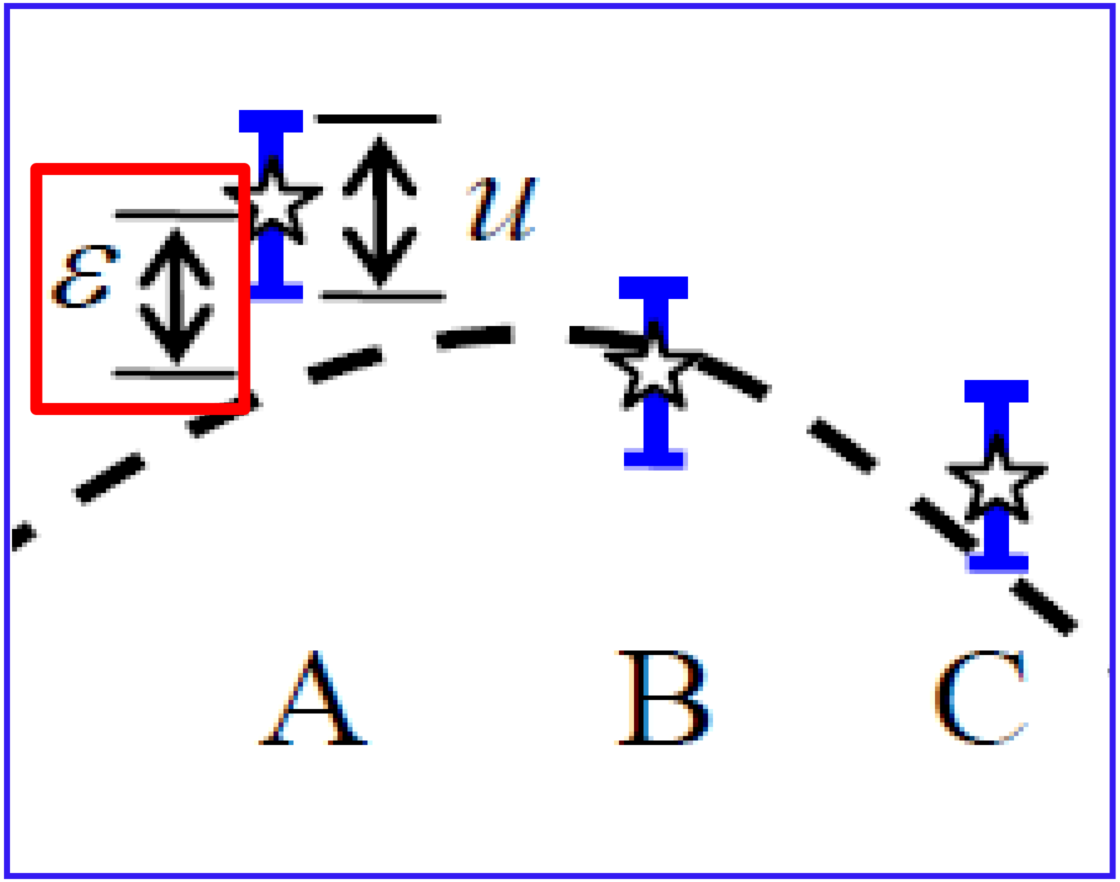
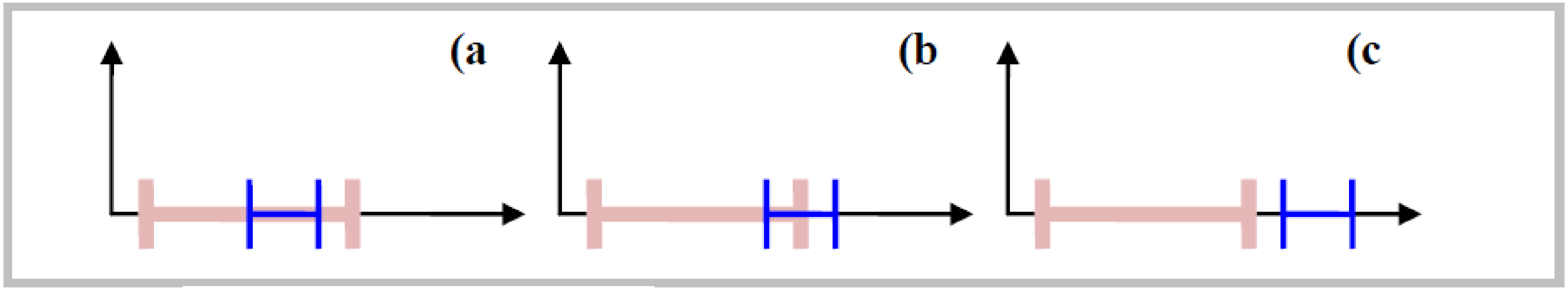


Data validation – detecting errors if they exist

Comparing measured and predicted values

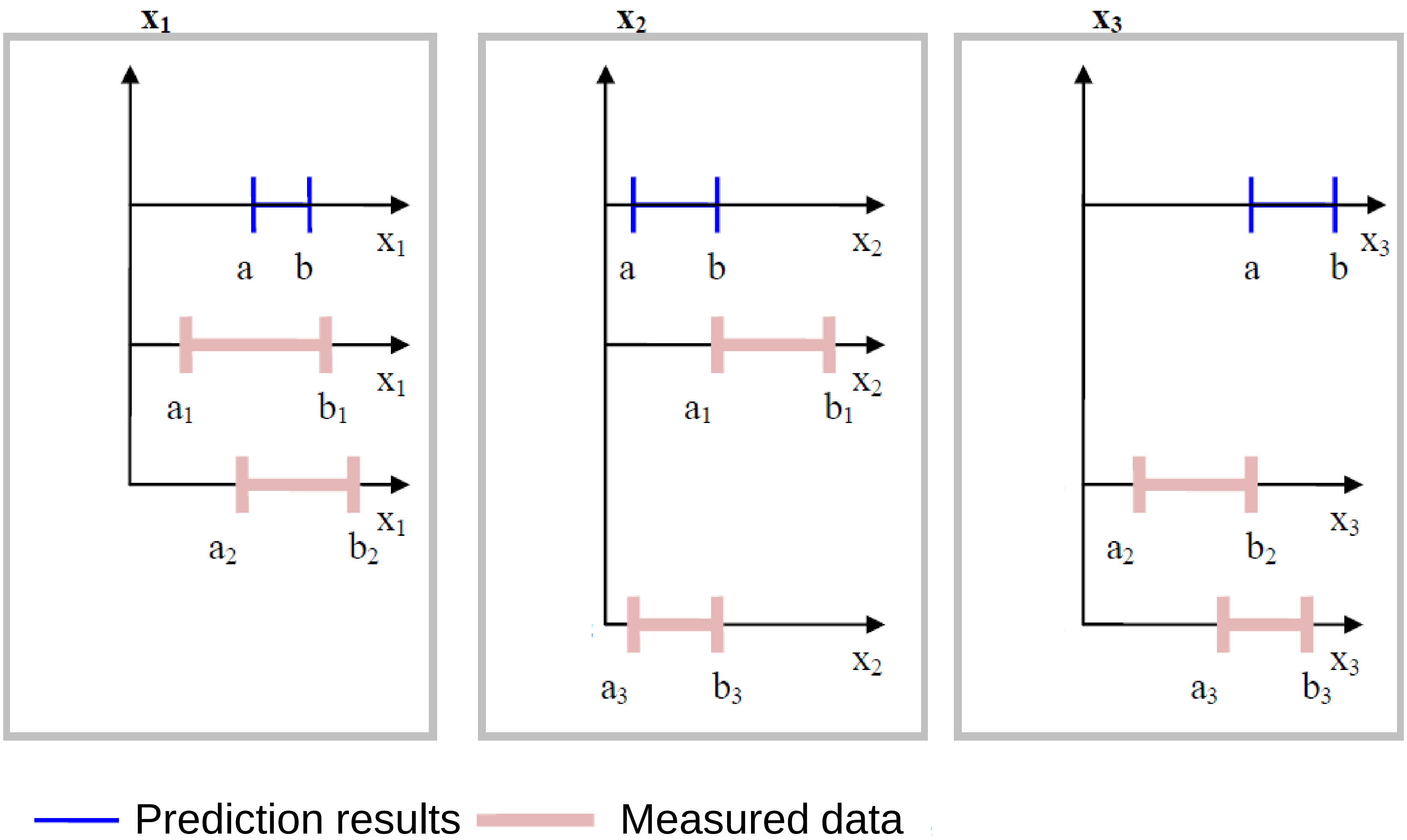
Measured and calculated values are presented with intervals



Prediction results Measured data

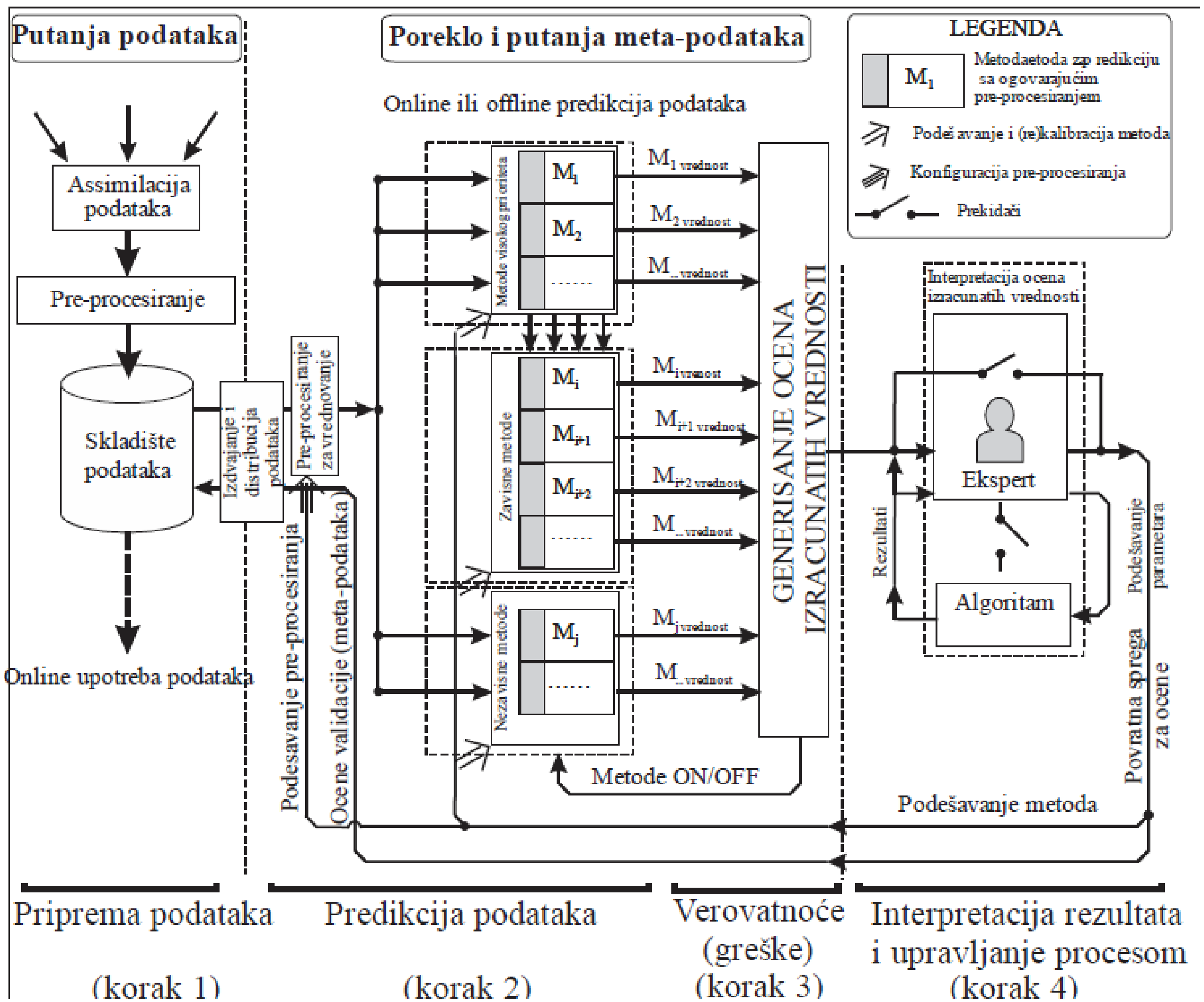
Enables detection of errors in data – data validation

Comparing measured and predicted values -complex system-

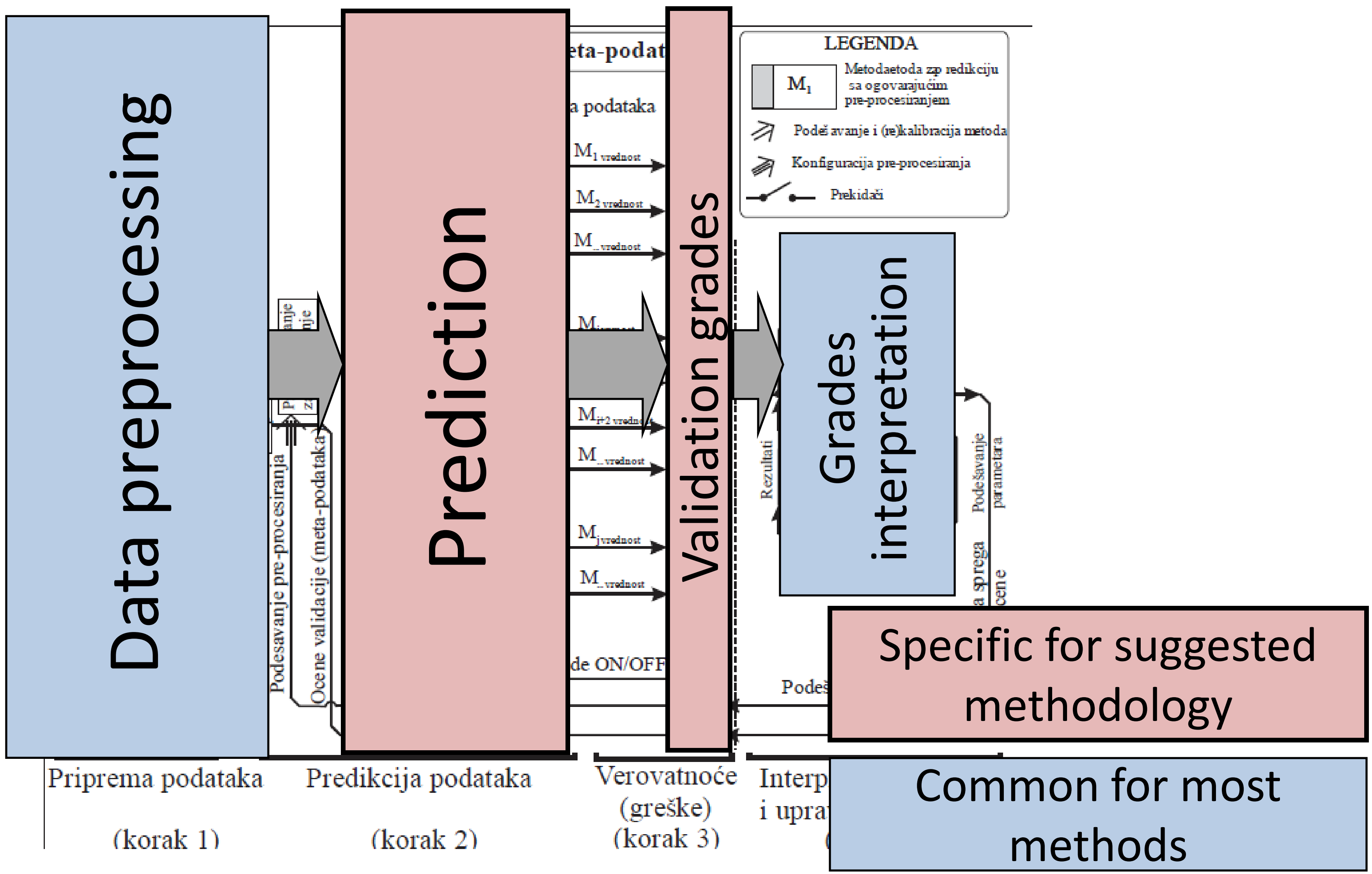


Suggested data validation methodology

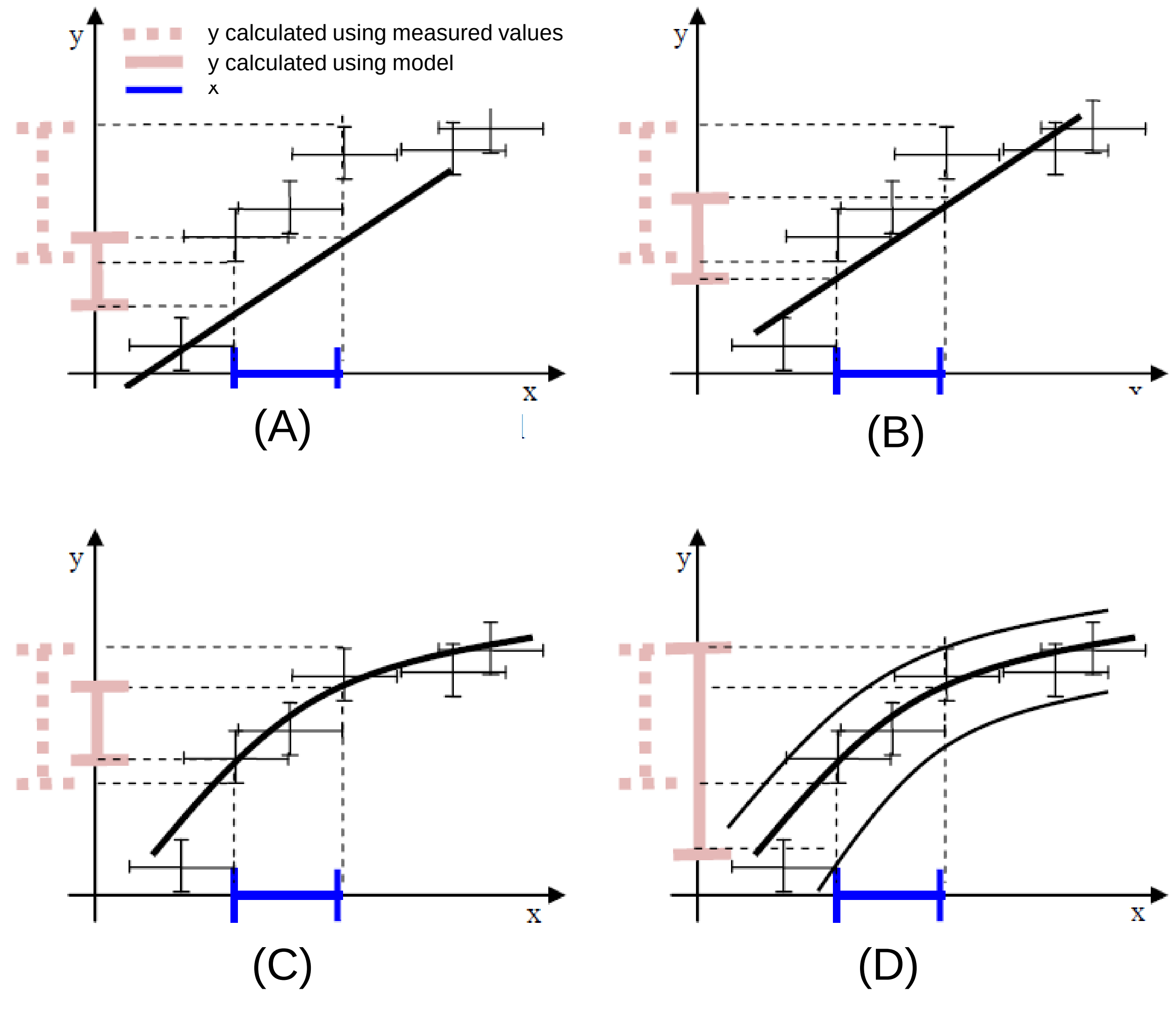
sorry for this mess on the screen – will make it more readable...



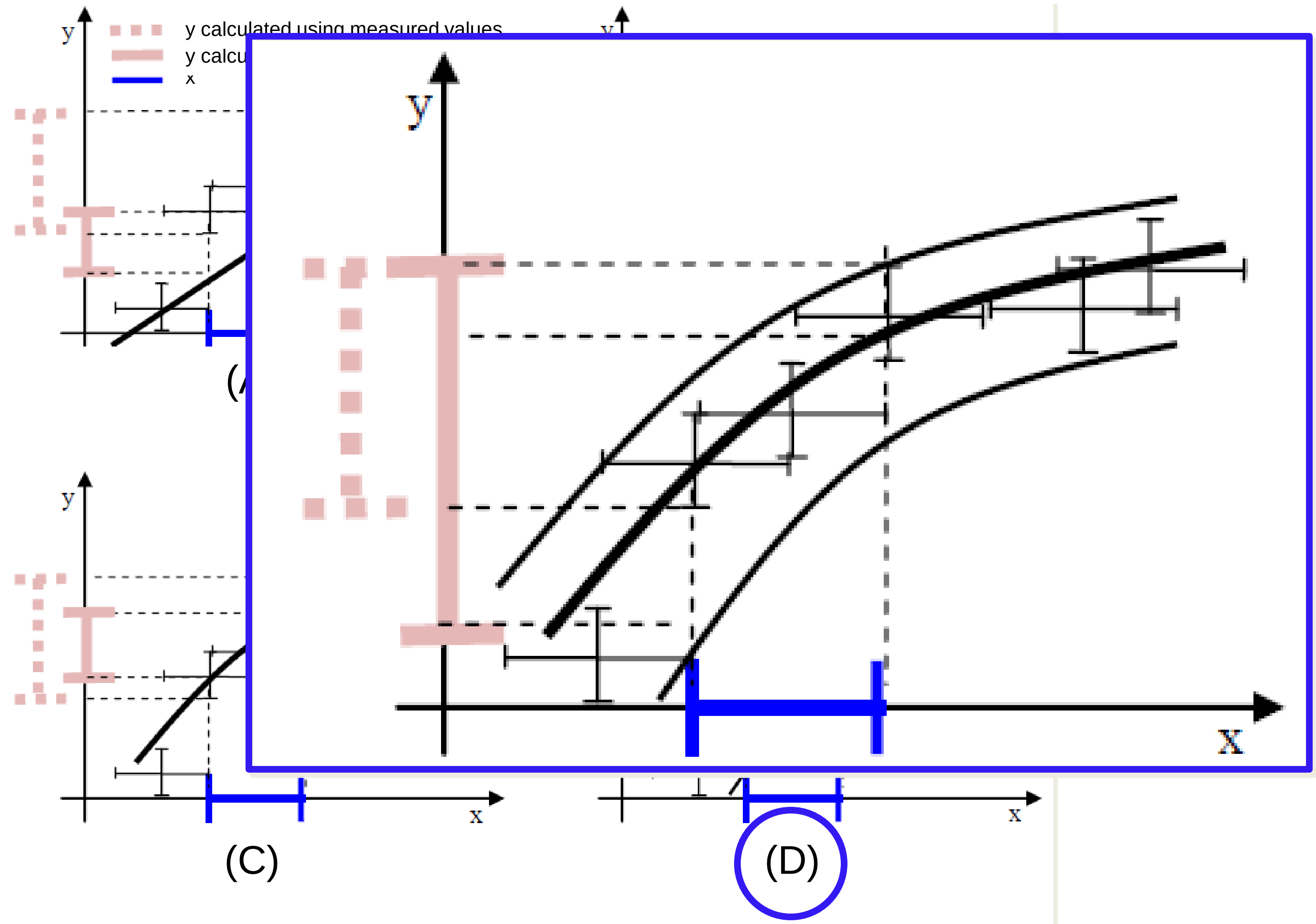
Suggested data validation methodology



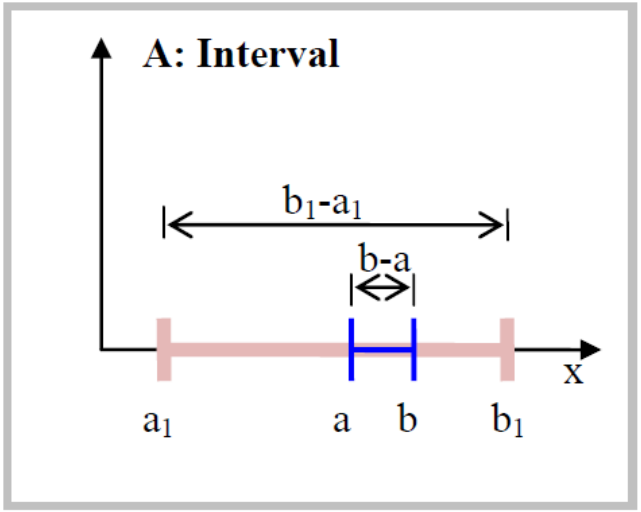
Data prediction
-relation errors and uncertainty-



Data prediction
-relation errors and uncertainty-



Validation grades
-data probability-



Prediction results

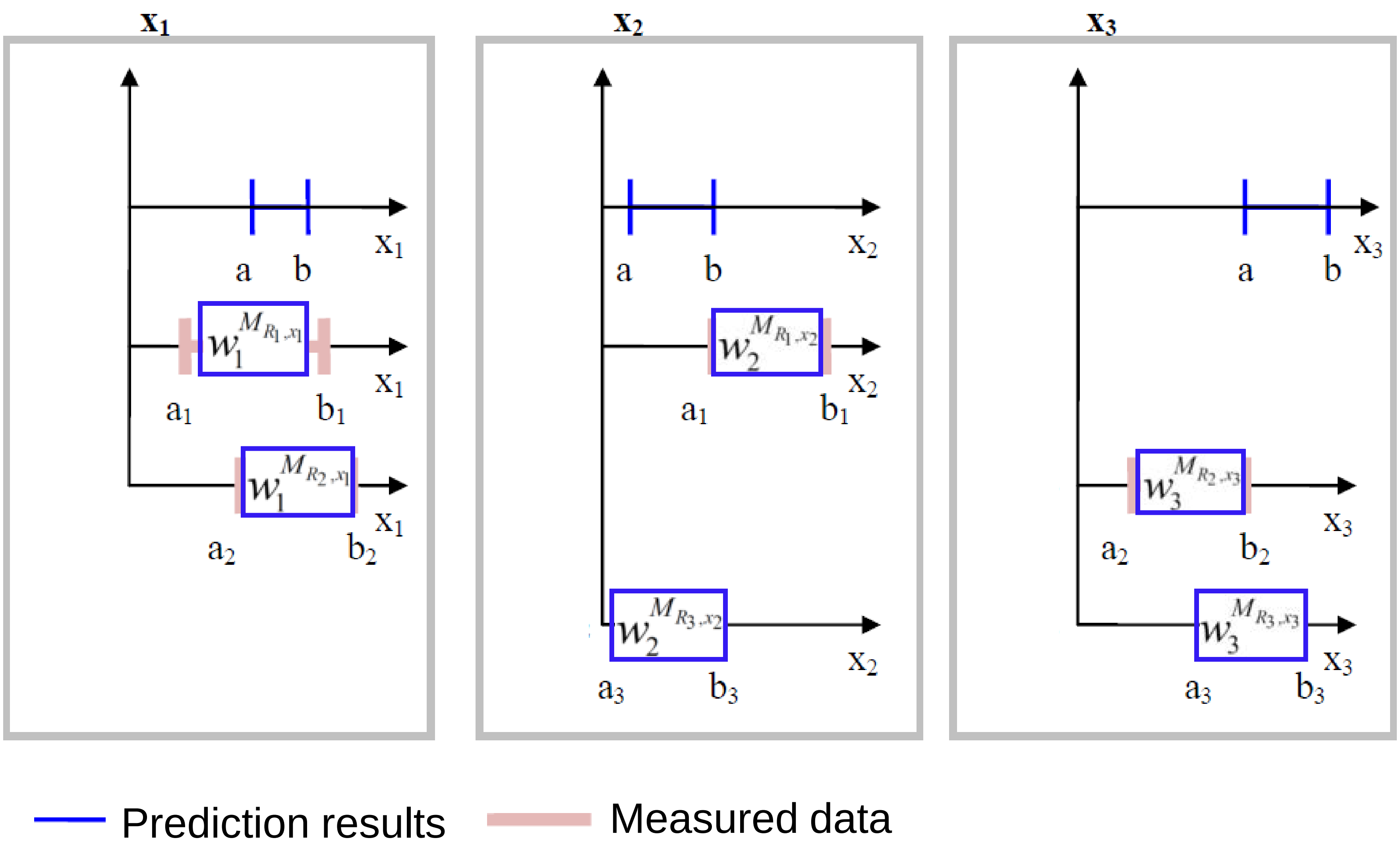
Measured data

$$p\left(\left[a,b\right]\mid\left[a_1,b_1\right]\right)=\frac{p\left(\left[a,b\right]\cap\left[a_1,b_1\right]\right)}{p\left(\left[a_1,b_1\right]\right)};$$

$$p\left(x_i \mid x_i^{M_j}, X_{x_i}^{M_j}\right)= p\left(\left[a,b\right]\mid\left[a_1,b_1\right]\right)=\begin{cases}1-\dfrac{\max\left(0,a-a_1\right)+\max\left(0,b_1-b\right)}{\left(b_1-a_1\right)}, & a_1\le b \\ & b_1\ge a \\ 0 & \end{cases}$$

$$\max\left(p\left(x_i \mid x_i^{M_j}, X_{x_i}^{M_j}\right)\right)=\max\left(P\left(\left[a,b\right]\mid\left[a_1,b_1\right]\right)\right)=\frac{b-a}{b_1-a_1}$$

Validation grades
-weighted average of data probabilities-



Validation grades
-likelihood of calculated values-

Weights– likelihood of predicted value

$$\boxed{w_i^{M_{R_j,x_i}} = p\left(x_i^{M_{R_j,x_i}} \mid X_{x_i}^{M_{R_j,x_i}}\right)}$$

Maximization of a sum of likelihoods - EM algorithm

$$\boxed{J = \max \sum_i \sum_j p\left(x_i^{M_{R_j,x_i}} \mid X_{x_i}^{M_{R_j,x_i}}\right)}$$

$\mathbf{E}$ step:

$$p\left(x_i^{M_{R_j,x_i}} \mid X_{x_i}^{M_{R_j,x_i}}\right) = \sum_{X_{x_i}^{M_{R_j,x_i}}} \left(\frac{\partial M_{R_j,x_i}\left(X_{x_i}^{M_{R_j,x_i}}, \theta\right)}{\partial X_{x_i}^{M_{R_j,x_i}}} \right)^{-1} P_{x_i}$$

$\mathbf{M}$ step:

$$P_{x_i} = \sum_j p\left(x_i \mid x_i^{M_{R_j,x_i}}, X_{x_i}^{M_{R_j,x_i}}\right) \times \frac{p\left(x_i^{M_{R_j,x_i}} \mid X_{x_i}^{M_{R_j,x_i}}\right)}{\sum_j p\left(x_i^{M_{R_j,x_i}} \mid X_{x_i}^{M_{R_j,x_i}}\right)}$$

Validation grades
-grades-

1. Not normalized $$\boxed{x_i^{grade} = \sum_j w_i^{M_{R_j,x_i}} \times p\left(x_i \mid x_i^{M_{R,x_i}}, X_{x_i}^{M_{R,x_i}}\right)}$$ (*between 0 and a<1*)

2. Normalized $$\boxed{x_i^{grade} = p_{x_i}^{norm} = \left(\sum_{x_i} w_i^{M_j} \frac{p\left(x_i \mid x_i^{M_{R_j,x_i}}, X_{x_i}^{M_{R_j,x_i}}\right)}{\max\left(p\left(x_i \mid x_i^{M_{R_j,x_i}}, X_{x_i}^{M_{R_j,x_i}}\right)\right)}\right)}$$ (*between 0 and 1*)

Evaluating validation systems

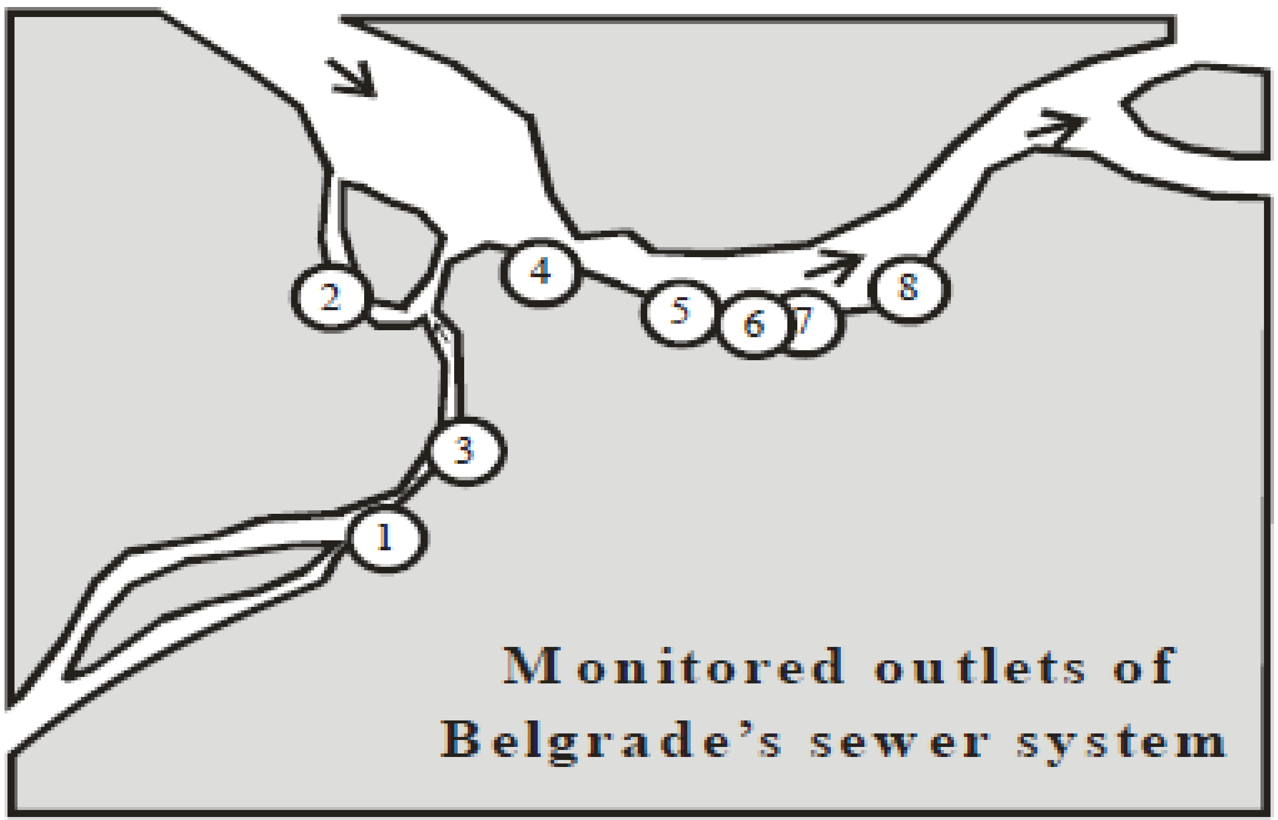
$$p = \frac{N_{registered}}{N_{anomalies} + N_{missed} + N_{registered\ nonanomalies}}$$

Comparing to Kappa index of coincidence:

- Higher penalty to missed anomalies, and
- Lower penalty to correct values interpreted as anomalies

Case study

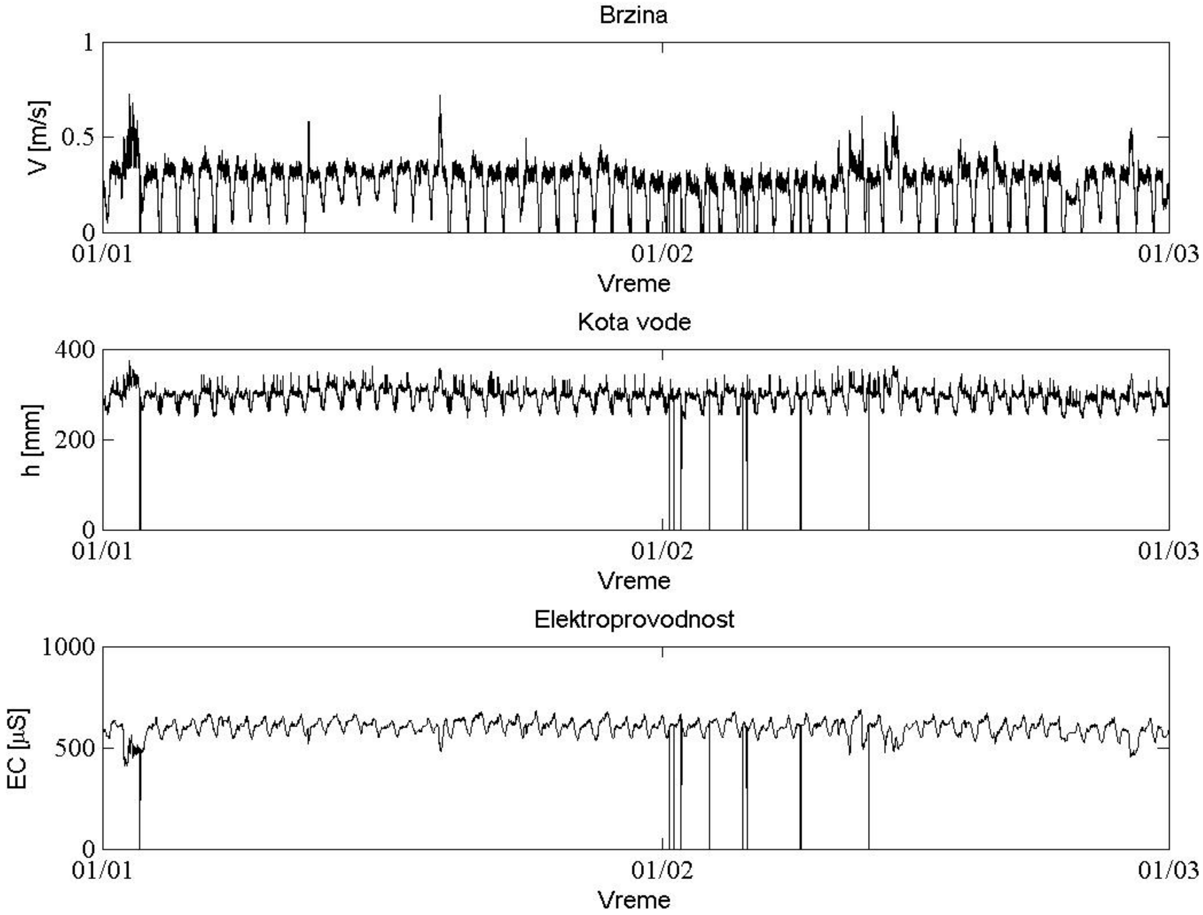
Measurements of hydraulic and water quality parameters in Belgrade sewer CSO



Measurements in Belgrade sewer CSO

Measured variables: Velocity (**V**), water depth (**h**), electro-conductivity(**EC**)

Period: 1/1/2007-1/3/2007



Relations between measured variables

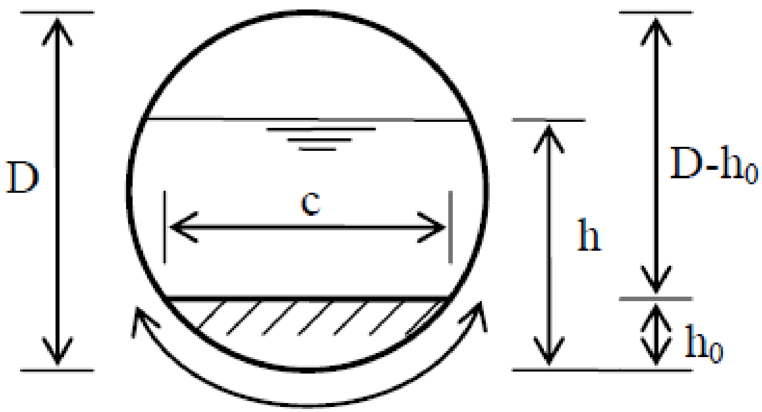
	V	h	EC	V^{t-1}	h^{t-1}	EC^{t-1}
R_1	$V^t = f_{V^t}^{R_1}\left(h^t\right)$	$h^t = f_{h^t}^{R_1}\left(V^t\right)$		$V^{t-1} = f_{V^{t-1}}^{R_1}\left(h^{t-1}\right)$	$h^{t-1} = f_{h^{t-1}}^{R_1}\left(V^{t-1}\right)$	
R_2		$h^t = f_{h^t}^{R_2}\left(EC^t\right)$	$EC^t = f_{EC^t}^{R_2}\left(h^t\right)$		$h^{t-1} = f_{h^{t-1}}^{R_2}\left(EC^{t-1}\right)$	$EC^{t-1} = f_{EC^{t-1}}^{R_2}\left(h^{t-1}\right)$
R_3	$V^t = f_{V^t}^{R_3}\left(EC^t\right)$		$EC^t = f_{EC^t}^{R_3}\left(V^t\right)$	$V^{t-1} = f_{V^{t-1}}^{R_3}\left(EC^{t-1}\right)$		$EC^{t-1} = f_{EC^{t-1}}^{R_3}\left(V^{t-1}\right)$
R_4	$V^t = f_{V^t}^{R_4}\left(V^{t-1}\right)$			$V^{t-1} = f_{V^{t-1}}^{R_4}\left(V\right)$		
R_5		$h^t = f_{h^t}^{R_5}\left(h^{t-1}\right)$			$h^{t-1} = f_{h^{t-1}}^{R_5}\left(h\right)$	
R_6			$EC^t = f_{EC^t}^{R_6}\left(EC^{t-1}\right)$			$EC^{t-1} = f_{EC^{t-1}}^{R_6}\left(EC\right)$

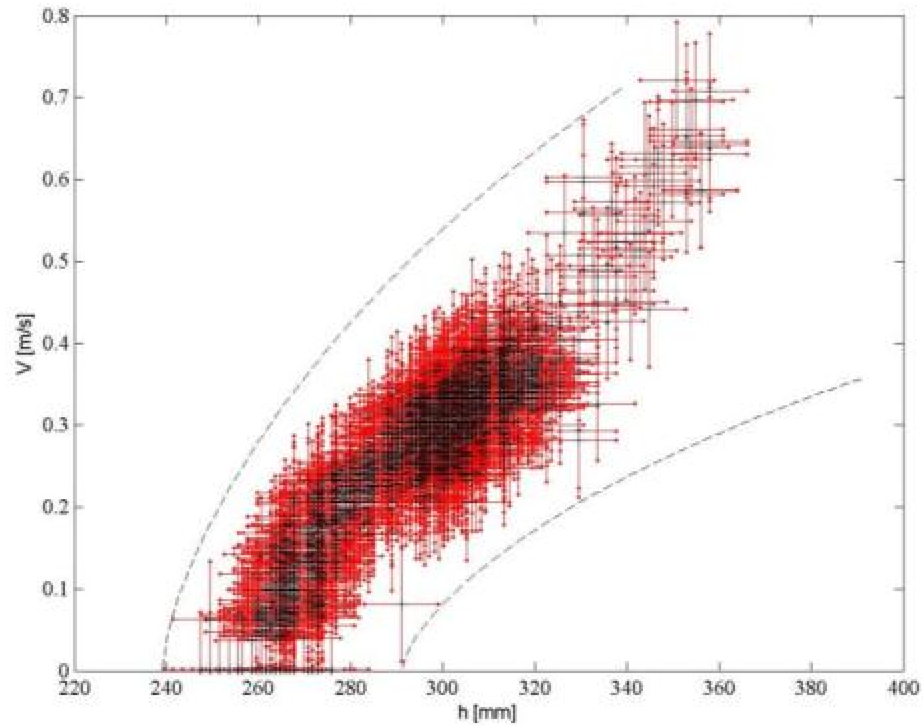
R1 – Chezy-Manning equation

R2, **R3** – Water quality model of EC reduction

R4, **R5**, **R6** – AR(1) models

Chezy-Manning equation





$$V(h_0, C, h) = C \times R(h_0, h)^{2/3}$$

$$C = \sqrt{I_d}/n$$

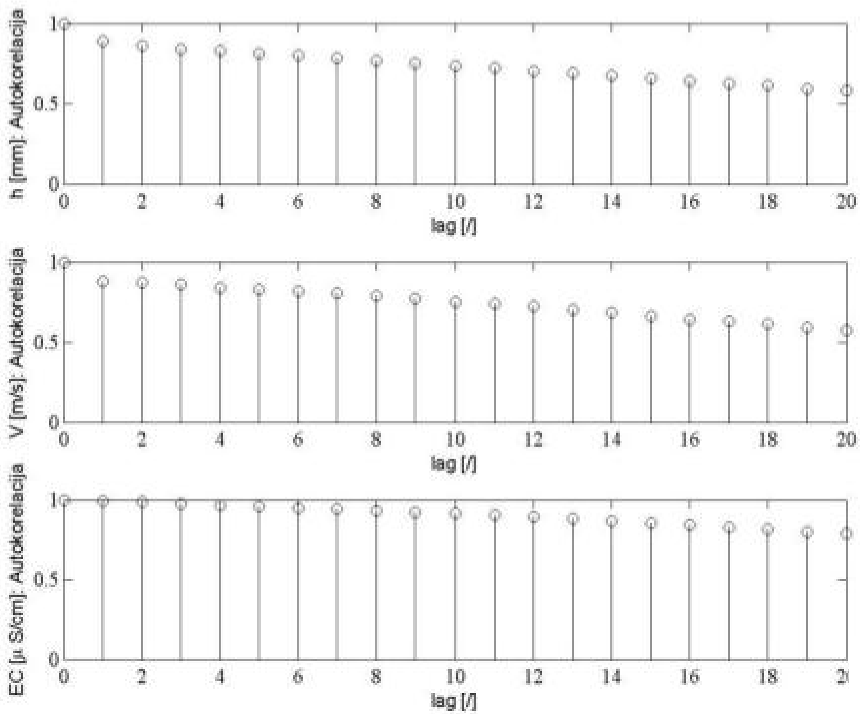
$$M_{R_1,V} : V(h) = [3.8, 1.9] \times R([239, 291], h)^{2/3}$$

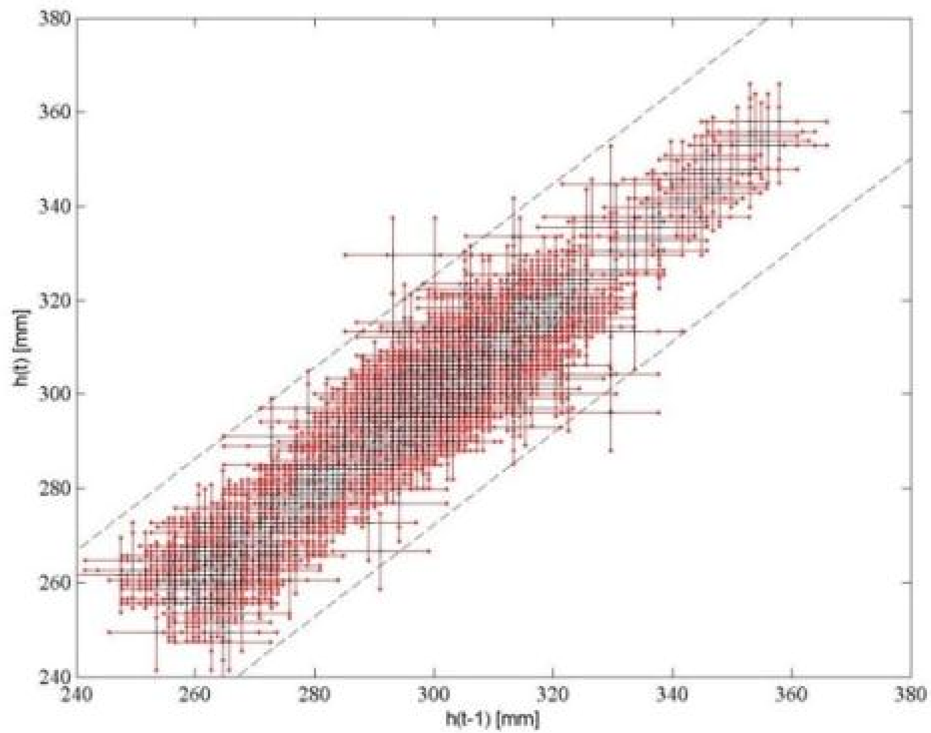
AR(1) models

$$x^t = ax^{t-1} + b$$

Autocorrelation coefficient

$$R_{ff}(\tau) = \int_{-\infty}^{\infty} f(t+\tau)\overline{f}(t)\,\mathrm{d}t$$



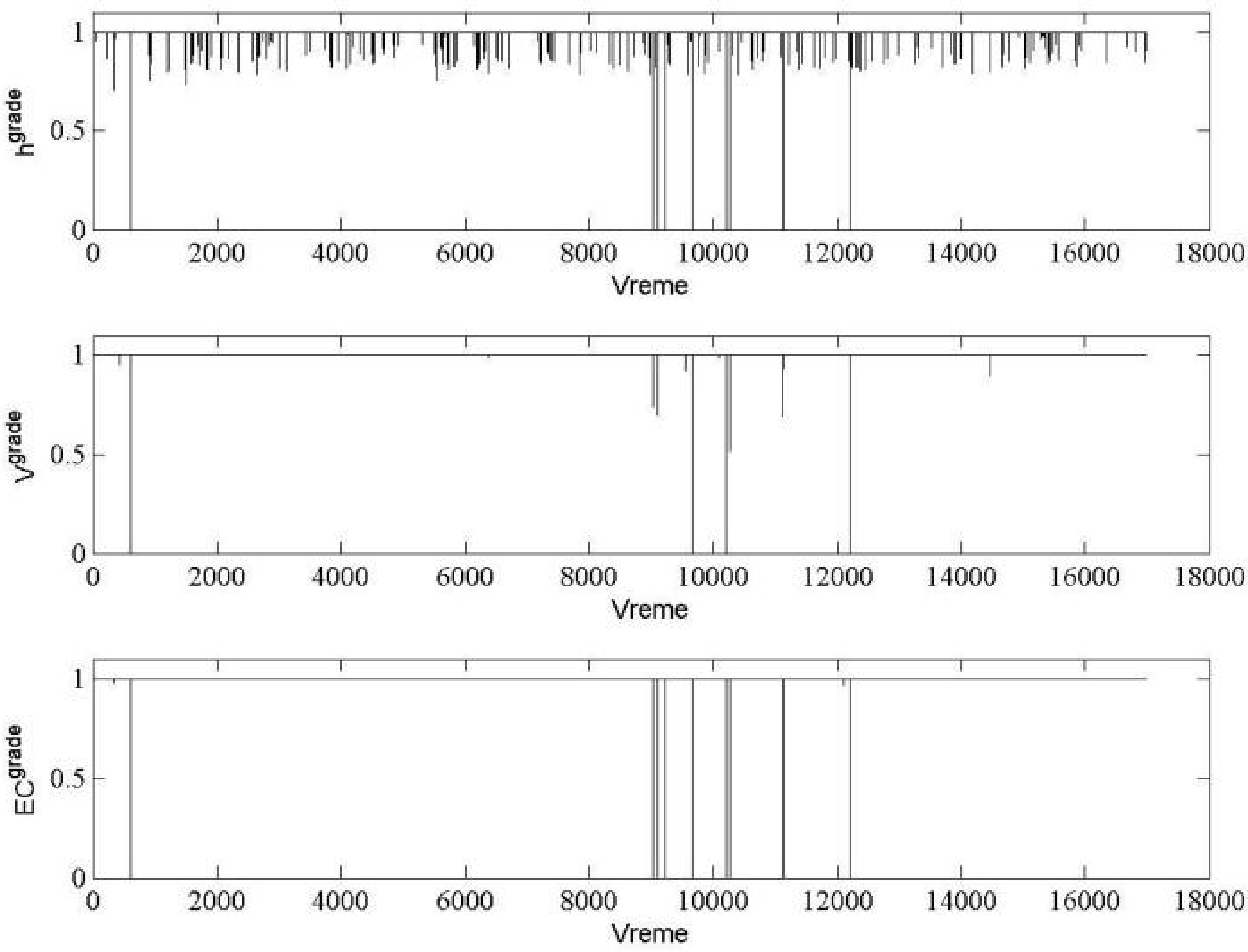


Model calibration results

x	h	V	EC
a	0.97427	0.97258	0.99712
$b=\left[\underline{b},\bar{b}\right]$	[-33, 52]	[-0.17, 0.19]	[-59, 49]

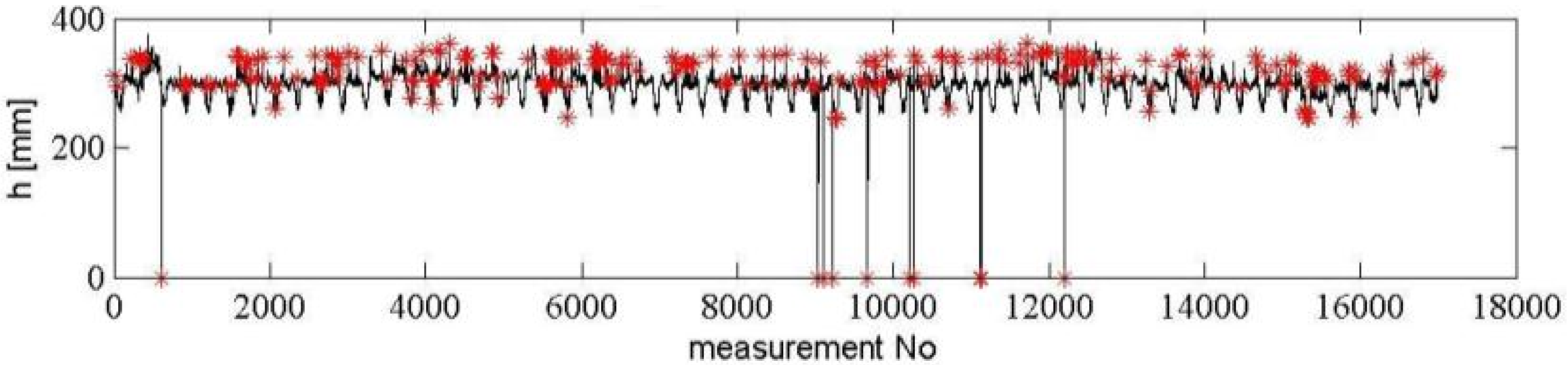
Results

-Validation grades-



Results
-comparison with manual data validation-

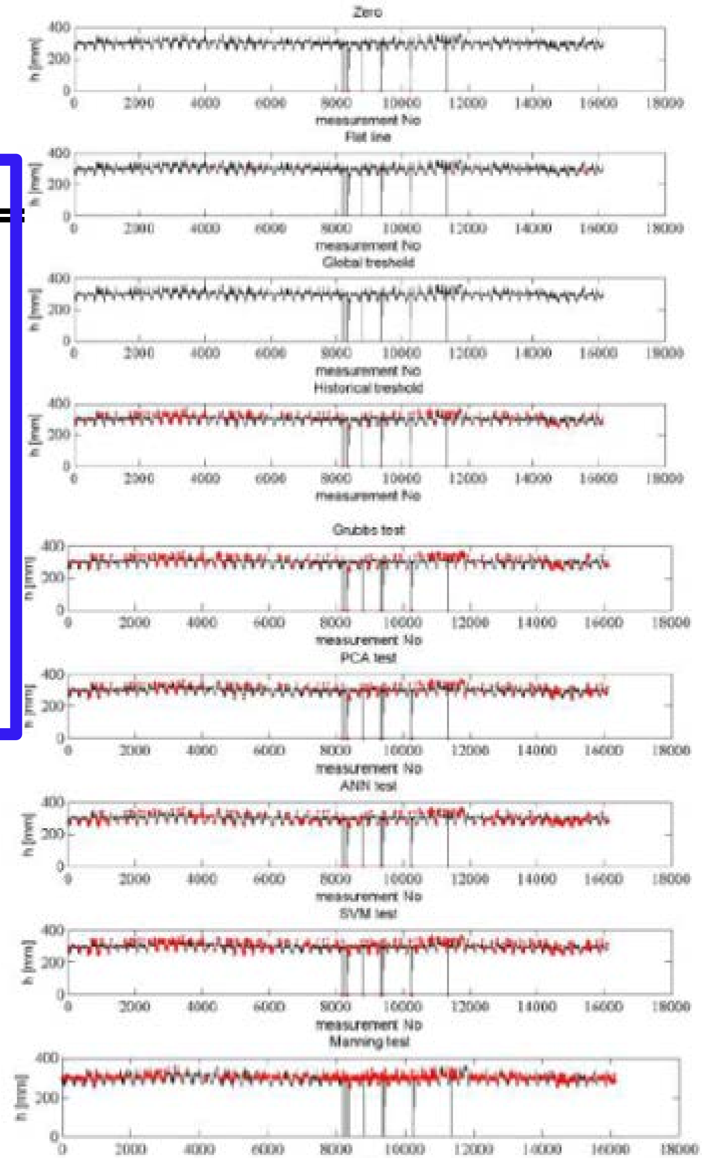
Threshold value= **0.99**



(No anomalies)	(No detected)	(No missed)	(No false)	p
244	219	25	73	0.64

Nine validation methods

	No anomalies	No detected	No missed	No false	p
M_1	244	24	220	0	0.052
M_2	244	0	244	28	0.000
M_3	244	0	244	0	0.000
M_4	244	202	42	220	0.399
M_5	244	187	57	334	0.294
M_6	244	224	20	359	0.360
M_7	244	109	135	896	0.085
M_8	244	237	11	483	0.321
M_9	244	71	173	2725	0.023



Averaging validation results:

$$p = \frac{N_{registered}}{N_{anomalies} + N_{missed} + N_{registered\ nonanomalies}} = \frac{195}{244+49+58} = \boxed{0.56}$$

Conclusions

- New theoretical framework for data validation
- No restrictions about number and type of additional information that may be used in the validation process
- No restrictions of type and number of relations that may be used
- The validation system may be evaluated and improved by improving the relations between the data values

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