

Interactive comment on “Real-Time Hydraulic Interval State Estimation for Water Transport Networks: a Case Study” by Stelios G. Vrachimis et al.

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We would like to thank the Reviewer for the positive evaluation and for providing constructive feedback, which helped us improve the quality the manuscript. The answers to the Reviewers' comments follow, indicated in italics:

1. In Line 34, Page 2, “Any uncertainty parameters in pipe j ...” should be substituted by “Any uncertain parameters in pipe j ...”

It has been corrected. Thank you.

2. In equation (1), Page 3, description of matrices A12 and A21 is missing.

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The description of the matrices is now included.

3. In Line 3, Page 4 it is stated; “the special structure of (1) can be exploited”, however no reference to the nature of this exploit or structure characteristics was provided.

More information about the structure of (1) and how it can be exploited is included in the revised manuscript.

4. The criterion for convergence in the change of bounds found at Line 14, Page 4, describes that was chosen to be “smaller than a specified small number ϵ ”. However, no description of the actual chosen value or criteria for its definition is found. For reproducibility of results or use of the method, a further explanation of the selection of the convergence criteria would be adequate.

More information about the convergence criteria is included in the revised manuscript.

5. In Line 8, Page 3 the description of the measurement uncertainty informs that the actual measurement is considered as the median of the interval value. However, in Line 30 of the same page, it is mentioned that the measurement is taken as the mean value of the interval. Although median and mean will present the same value in a 2-point interval, a consistent description would be more adequate.

This has been corrected.

6. The method under discussion is supposed to consider measurement and modelling uncertainties. It is recognised that modelling uncertainties are understood

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only as parametric uncertainties (e.g. Line 9, Page 5 and Line 5, Page 1). However, this is an incomplete description of the uncertainties arising from a mechanistic model simulator. Additionally, at Line 10, Page 5, it is stated that parametric uncertainty was assumed to have a value of “ $\pm 2\%$ of the Hazen-Williams coefficient”. This could be a legit expert-elicited model parametric uncertainty. However, this does not guarantee a correct model uncertainty description since it neglects the effect of structural uncertainty. This could be corrected in two ways; a) including an extra term in the equation (1) which represents a model structural error-generating process, or b) explicitly stating in the document that modelling uncertainties are approximated only by an expert-elicited parametric range, and discussing the adequacy of this range to represent the full model predictive uncertainty in a realistic manner.

It is assumed that the network graph is known, thus structural uncertainty is neglected. This is a valid assumption in transport networks where the structure is not complicated as in this case study. The parameter uncertainty, i.e. pipe lengths, diameters and roughness coefficients, can be estimated by experts. This is now clarified in the text. Thank you.

7. At the introduction section, Line 12, Page 2, there is a reference for previous works on “A straightforward method for interval state estimation” by using Monte-Carlo simulations. This is accepted to converge to the true uncertainty bounds of the prediction variables under certain assumptions. A simple random sampling approach of the model-measurement space could provide a full description of the probability density function of the predicted variables, which can readily be transformed to a confidence interval of values and easily integrated into a probabilistic system assessment (facilitating risk assessment etc.). However, the methodology proposed by the authors, although mathematically feasible will only provide a range of parameter values, which do not have a probabilistic interpretation. It is missing a proper justification of the benefits of using the new interval-based



approach rather than a Monte-Carlo based sampling. This could perhaps be illustrated with a gain in computational speed, however, no information was provided to justify those gains.

We thank the Reviewer for raising this issue for clarification. The interval-based approach used in this paper has the advantage of calculating algorithmically the bounded state estimates in a way that guarantees the inclusion of the true state. Monte-Carlo Simulations (MCS), even with a large number of simulations, cannot guarantee that all the possible cases will be simulated. The applicability of the proposed algorithm is thus suitable for event and fault-detection methodologies that require strict bounds on state estimates.

Regarding the computational time, it can be shown that the IHISE algorithm needs less time to compute bounds compared to a large number of MCS. However, even with a large number of MCS it is still not guaranteed that the true state is included. In the revised manuscript, these issues are discussed and further clarified.

8. In Figure 4, Page 7 the authors show a comparison of the interval values of estimated outlet bounds by IHISE and of the outlet bounds calculated by a volume balance between level and inflow measurements. Flow estimations from the data assimilation scheme of the full system present an appreciable narrower interval than those from the tank volume balance. This difference can be due to three reasons:

- a. The method works well and a data assimilation scheme produces enough information to narrow down significantly the predicted state variable.
- b. The measurement uncertainties in the inflow monitoring stations and in the tank depth are relatively large and this is transferred to the estimated outflow.
- c. The uncertainty in the measurement-derived outflow is reasonable.

However, a limited description of modelling uncertainties in the state estimation produces overconfident interval values, thus underestimating the uncertainties of



the estimated outflow. This should be carefully addressed in the discussion of the presented results since it is critical for validating the credibility of the estimated estate intervals.

The tank outflow bounds estimation from the tank volume balance is larger than those produced by the algorithm because of the use of interval arithmetic operations for the calculations, which inherently overestimate the intervals. This indicates the need for different techniques for the calculation of intervals, thus the use of the IHISE algorithm.

To address the concerns of the Reviewers, in the revised manuscript this comparison is replaced with a demonstration of simple mass balance and comparison with the bounded estimates derived by the algorithm in a looped network.

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