ESTAN Toolbox and Multiobjective Model Based Design of Experiments - Getting the Most Out of Data and Models

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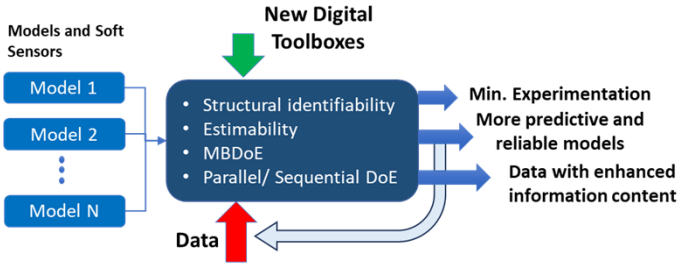
1. Background and Motivation

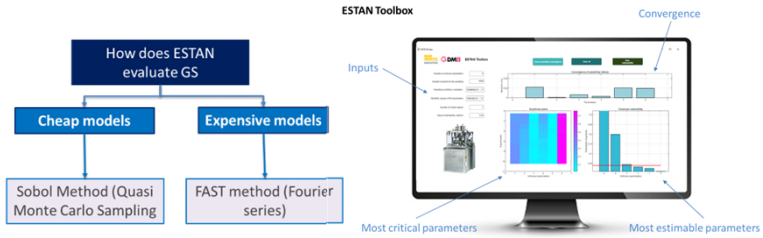
- Most Mathematical models and digital twins suffer from poor prediction capabilities due to issues inherent to model structure, lack of experimental data, and most importantly uncertainties and poor information content of the data.
- The development of effective digital quality control systems requires reliable and accurate mathematical models.
- To develop predictive and reliable models, it is critical to assess structural identifiability and estimability (practical identifiability) to determine whether the available data contain enough information to identify more reliably all or some model parameters
- Model-based DoE can minimize the experimentation efforts and costs while

2.ESTAN Toolbox

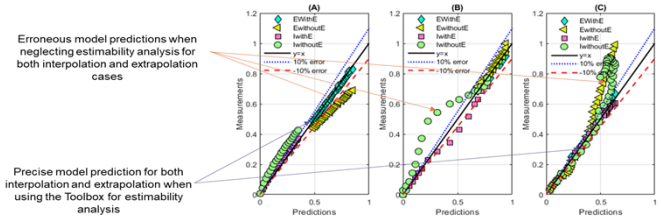
- A new toolbox, ESTAN, is proposed to allow systematic assessment of the information content of data to build more predictive mathematical models.



- ESTAN uses cost-effective global sensitivity analysis to run the estimability analysis allowing better evaluation of the data information content.
- ESTAN informs on what are the model parameters that can reliably identified from the data. It can be combined with MBDoE to identify the experiments that can generate data with sufficient information content to maximize model perdition capabilities.



- Three different type of mathematical models were considered to validate ESTAN's capabilities. All models delivered enhanced prediction capabilities after the implementation of the etimability approach



(A): Case of the non-dynamic model. (B): Case of the dynamic model. (C): Case of the algebric expression-based model.

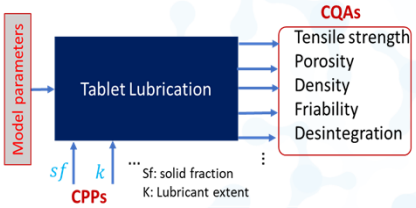
3. MOMBDoE

- A new Multiobjective Model-Based Design of Experiments (MOMBDoE) is proposed to deliver experiments with guaranteed maximum information content and reduced parameter uncertainties.

Case study: Tablet Lubrication, Kushner and Moore model.

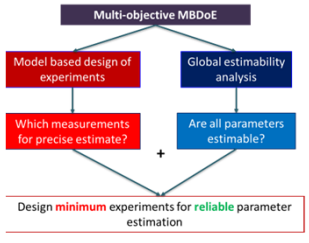
CQAs: Tensile strength (*ts*) and Hardness (*H*)

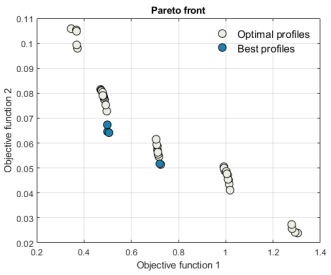
CPPs: Lubricant Extent and Solid Fraction

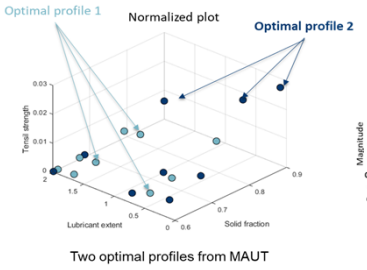


$$\frac{ts}{ts_{sf=0.85,0}} = (1-\beta) + \beta\exp(-\gamma k)$$

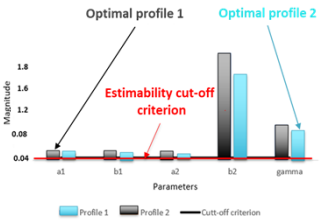
$$H = \frac{ts\pi D^2}{10}\left(2.84\frac{\sigma}{D} - 0.126\frac{\sigma}{\sigma - 2\sigma_c} + 3.15\frac{\sigma - 2\sigma_c}{D} + 0.01\right)$$



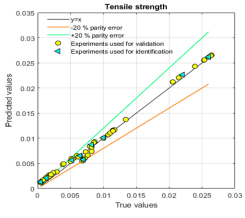


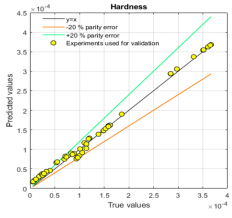


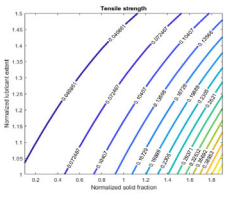
Two optimal profiles from MAUT

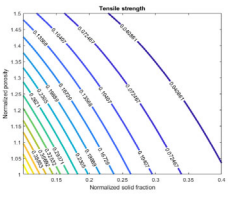


- The solution of the MOMBDoE problem is capture by the Pareto front which represents the best compromises between both objective functions.
- Two best solutions were identified from the Pareto set based on a multicriteria decision aiding method.
- Model prediction were enhanced as shown in the parity plots.
- More reliable Design Spaces can be obtained for both CQA.









4. Conclusions

- A new toolbox, ESTAN, for effective estimability analysis was developed and validated using steady state, dynamic and purely algebraic mathematical models. ESTAN can be used to assess whether the available experimental data allow reliable identification of some, all, or none of the model parameters.
- ESTAN's adaptability to both computationally cheap and expensive models, utilizing Sobol and FAST methods to enhance model prediction capabilities.
- By automating laborious tasks, the ESTAN toolbox simplifies the process of the estimability analysis for researchers.
- A novel Multi-objective model-based design of experiments framework was developed to identify effective and optimal experimental campaigns.
- Top-ranking solutions of the Pareto were validated and demonstrated enhanced model prediction capabilities.

REFERENCES:

- B. Benyahia, M. A. Latifi, C. Fonteix, F. Pla. (2011b). Multicriteria dynamic optimization of an emulsion copolymerization reactor. Computers & Chemical Engineering, 35(12), 2886-2895.
- D. Fysikopoulos, B. Benyahia, A. Borsos, Z. K. Nagy, C. D. Rielly, (2019), A framework for model reliability and estimability analysis of crystallization processes with multi-impurity multi-dimensional population balance models. Computers & Chemical Engineering, 122, 275-292.
- J. Kushner, F. Moore, (2010), Scale-up model describing the impact of lubrication on tablet tensile strength, International journal of pharmaceutics, 399(1-2), 19-30.
- X Yuan, B Benyahia (2023) A Combined D-optimal and Estimability Model-Based Design of Experiments of a Batch Cooling Crystallization Process. Computer Aided Chemical Engineering 52, 255-260.
- I Bouchkira, AM Latifi, B Benyahia (2023) ESTAN–A toolbox for global sensitivity based estimability analysis. Computer Aided Chemical Engineering 52, 439-444
- I Bouchkira, B Benyahia (2023) Multi-Objective Model-based Design of Experiments of Pharmaceutical Tableting Process. Computer Aided Chemical Engineering 52, 349-354

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