Report on the Short-Term Scientific Mission at Tilburg University

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The goal of this short-term scientific mission was to establish a collaboration between researchers from FAU and from Tilburg University in order to study challenging two-stage robust optimization problems that occur in energy networks. More specifically, we have focused on the technical operation of gas networks.

The motivation stems from the fact that for many real-life problems some parameters can only be estimated roughly. A well-known example in gas network optimization is the roughness value of the pipe that influences the friction of the gas and thereby effects the pressure loss between the endpoints of the pipe. However, the roughness depends on the contamination of the pipe and can only be measured with great effort. Furthermore, there are methodological uncertainties from the approximation of nonlinear functions in the context of mixed-integer linear optimization problems (MIPs). The corresponding research questions are currently studied within subproject B06 (D. Aßmann, F. Liers, M. Stingl, all FAU) of the Transregional Collaborative Research Center 154 that is funded by the DFG. For more details, see `www.trr154.fau.de`.

In the robust optimization setting of B06, continuous state variables are categorized as adjustable ("wait-and-see"), whereas binary decision variables are modeled as static or "here-and-now" variables. The robustification of the mentioned problem leads to mixed-integer linear, conic quadratic or positive semidefinite optimization problems, depending on the given uncertainty set and the occurance of the uncertain data. These different modeling options are adapted for gas-network optimization.

During this short-term scientific mission, we started a scientific collaboration between Denis Aßmann and Prof. Dr. Frauke Liers (both FAU), with Prof. Dr. Dick den Hertog, Prof. Dr. Juan Vera, Dr. Ruud Brekelmans, and Krzystof Postek, all from Tilburg University who mainly use methods from robust and continuous non-linear optimization.

During the short-term mission, first the researchers from FAU introduced the robust optimization model to the colleagues in Tilburg. The researchers explained the solution approaches that have been developed in Erlangen. This includes a positive semidefinite optimization method that has been implemented within a branch-and-bound framework, as well as an approach that splits the uncertainty set and that extends an idea that was developed by den Hertog and Postek in recent work. In addition, Denis gave a seminar talk at Tilburg University about this work on robustification of physical parameters in gas networks on April 21th. Thus, the topic was introduced to a larger audience as well.

Up to now, the research at FAU has mainly been on algorithms for treating the general problem that model active elements, i.e., discrete decisions, as well as the continuous non-linear gas physics. Thus, methods from integer (non-linear) programming have mainly been developed and used.

During this short-term missing at Tilburg University, we complemented this work by focusing on several specific subproblems without active elements that are relevant for a robust treatment of gas networks. In particular, we focused on a robust treatment of passive networks with easy topology such as a tree as well as sparse tree-like networks that contain a few cycles only. For these topologies, we studied demand uncertainty as well as uncertainty in the roughness parameters.

For this work, we started from a preprint by Gotzes, Heitsch, Henrion, and Schultz ("Feasibility of nominations in stationary gas networks with random loads", 2015) in which algebraic formulations for the set of feasible nominations are given in the context we study here. Starting from their results, we studied the problem of deciding on *robust* feasibility under roughness and demand uncertainty.

We were able to characterize the tractability of the robust feasibility problem under demand uncertainty as well as under roughness uncertainty, in case the underlying network is a tree. Furthermore, we were able to model the robust feasibility problem for a network with cycles as an optimization problem over polynomials. The corresponding optimization model can then be solved with methods from polynomial optimization. To this end, we use a quadratic sums-of-squares approximation because the latter can be formulated as a positive-semidefinite program that can be solved well in practice. As the quadratic model is an approximation, it can verify correctly the case of robust *infeasibility*, whereas in general robust *feasbility* might not be decided for sure. We discussed in which special cases the quadratic program yields the exact answer on robust feasibility as well.

Finally, we discussed ways to apply robustness concepts to linear robust network flow problems.

This short-term scientific mission has been very stimulating and fruitful as it brought together discrete and continuous (robust as well as polynomial) optimizers in Tilburg. We worked together on gas networks very intensively. Such a collaboration otherwise would not have been possible. Very interesting discussions on robust gas network operations evolved. The joint work on this topic will continue even after this first visit in Tilburg.