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Synthesis and design of processing networks: decision making under uncertainty and sensitivity analysis

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For processing companies, the synthesis and design of optimal industrial operations include all the strategic and tactical decisions such as the selection of raw materials and products portfolio, as well as the synthesis and design of the processing network and the optimization of the material flows through it. The solution of this problem requires extensive cross-functional co-ordination through the corporation, as well as business management, operational and engineering expertise.

In previous studies we proposed an integrated business and engineering framework for synthesis and design of processing networks (Quaglia et al, submitted). The framework employs a modified formulation of the transhipment problem, integrated with a superstructure to consider non fixed topology. Through this approach, the problem is cast as a Mixed Integer Non Linear Program (MINLP), which is then solved to determine the optimal processing network.

By performing the simultaneous solutions of the business and engineering dimension of the open problem, the proposed methodology allows among others: i) to reduce the effort needed to solve the problem while improving the reliability of the solution and ii) to increase the impact of analysis techniques such as uncertainty and sensitivity analysis by extending their scope to the whole problem including the cross-functional issues.

This contribution provides a perspective on the integration of uncertainty and sensitivity analysis methods and tools within the synthesis and design framework, in order to extend the scope of the application to decision making under uncertainty.

First, the main sources of uncertainty are screened, identified and characterised with respect to probability distributions. Three categories of uncertainty are distinguished to structure the screening of sources of uncertainty as follows: i) technical uncertainty, related to the technical performances of the processes and models, ii) market uncertainty, related to market prices and demands or availability and iii) input uncertainty, related to raw materials or input compositions and flows. Each uncertain factor is characterized in terms of probability distribution and correlation with the other uncertain factors (Sin et al, 2009).

Then the problem of decision-making under uncertainty is formulated for the identified uncertain factors. Stochastic programming techniques are employed to solve the problem, in order to identify the optimal solution while ensuring feasibility over the entire uncertain domain.

Finally, the impact of each uncertain factor on the decision making process and on the performances of the solution is evaluated by performing sensitivity analysis. The sensitivity analysis results provide sensitivity measure for each uncertain factor, which is used to rank the significance of factors' contribution to the uncertainty of performance metrics. This ranking provides the list the most critical factors, which is used as a rationale for value oriented prioritization of technical and commercial activities (the higher the magnitude of sensitivity measure is, the higher the priority of that factor is).

In order to demonstrate and highlight the application of the framework, industrial case studies dealing with the synthesis and design of processing networks in food processing and water treatment are formulated and solved. The main sources of uncertainty are identified and characterized. The problem of decision making under uncertainty is formulated and solved to identify the optimal processing network, and the uncertain parameters are ranked with respect to their impact to the decisions making process and results. Finally, the results are used to propose strategies for dealing with the most important sources of uncertainty.

A. Quaglia, B. Sarup, G. Sin & R. Gani, 2010, Integrated Business and Engineering Framework for Synthesis and Design of Enterprise-Wide Processing Networks, Computers and Chemical Engineering (submitted)

G. Sin, K. Gernaey & A.E. Lantz, 2009, Good modeling practice for PAT applications: Propagation of input uncertainty and sensitivity analysis, Biotechnology Progress, 25 (4), 1043-1053.