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Integrated business and engineering framework for synthesis and design of enterprise-wide processing networks

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ABSTRACT

The synthesis and design of processing networks is a complex and multidisciplinary problem, which involves many strategic and tactical decisions at business (considering financial criteria, market competition, supply chain network, etc.) and engineering levels (considering synthesis, design and optimization of production technology, R&D, etc.), all of which have a deep impact on the profitability of processing industries.

In this study, an integrated business and engineering framework for synthesis and design of processing networks is presented. The framework employs a systematic approach to manage the complexity while solving simultaneously both the business and the engineering aspects of problems, allowing at the same time, comparison of a large number of alternatives at their optimal points. The results identify the optimal raw material, the product portfolio and select the process technology for a given market scenario together with the optimal material flows through the network and calculate the corresponding performance and sustainability metrics.

The framework includes a software infrastructure for integrating different methods and tools needed for problem definition, formulation and solution of the design problem as a MINLP, reducing thereby the time and cost needed to generate and solve the design/synthesis problems and providing efficient data transfer between the tools. A generic structural process model has been implemented within the framework to describe the multidimensional engineering issues allowing thereby fast and flexible model development for various production processes.

A case study from vegetable oil industry is used successfully to demonstrate the applicability of the integrated framework for making optimal business and engineering decisions.

1. Introduction

Processing industries are in general organized in a functional structure, with separate departments working in a coordinated and integrated manner on enterprise-wide projects. The harmonic synchronization and integration between different functions is for large companies a necessary condition for obtaining the complete business potential of its activity (Williams & Samset, 2010).

An important example of enterprise-wide problems is the synthesis and design of processing networks. This involves a combination of strategic decisions (such as the selection of the product portfolio, of the raw materials and of the process technology) and of tactical decisions (the determination of the optimal processing conditions, of the optimal material flow through the processing network, etc.). Examples from this class of problems are multiple, and include new plant construction, retrofit of existing operations and capacity expansion, utility generation and waste processing.

In industrial practice, this problem (which is often described as "do the right project, do the project right") is tackled by the coordinated work of business and process engineering departments. A business department deals with the layer of strategic decisions and screening of alternatives to select the right project to execute on the basis of strategic considerations, employing financial and economical tools or indicators such as Balanced Scorecard and project NPV. On the other hand, process engineering deals with the layer of tactical decisions, related to design and optimization of the selected alternative with the help of tools such as process simulators.

Decomposing of the problem into two layers (strategic and tactical) and solving them separately one at a time has some drawbacks. First of all, two layers of decomposition are not independent but interdependent, since the calculation of economical indicators for

Abbreviations: CAPEX, capital investment; GOM, gross operating margin; NPV, net present value; MMT, millions metric tonnes.

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Nomenclature

Indexes

i	component
k	process interval (origin)
kk	process interval (destination)
$react$	key reactant
rr	reaction
t	time (years)

Parameters

MW_i	molecular weight
$P1_{i,kk}$	raw materials prices
$P2_{i,kk}$	utilities prices
$P3_{i,kk}$	products prices
$P4_i$	wastes disposal price
$SW_{i,kk}$	wastes fraction
$S_{k,kk}$	superstructure (binary)
$W_{k,kk}$	specific transportation cost
a_{kk}	coefficient for capital cost estimation
$dist_{k,kk}$	transportation distance
n_{kk}	coefficient for capital cost estimation
$\alpha_{i,kk}$	specific utility consumption
$\gamma_{i,kk,rr}$	reaction stoichiometry
$\varepsilon_{i,k,kk}$	split factors
$\theta_{react,kk,rr}$	conversion of key reactant
$\mu_{i,kk}$	fraction of utility mixed with process stream
dr	discount rate

Variables

$F_{i,k,kk}$	component *i* flow from process intervals *k* to process intervals *kk*
$ff_{i,kk}$	component flow after mixing
$R_{i,kk}$	utility flow
$F^M_{i,kk}$	component flow after mixing
$F^{out}_{i,kk}$	component flow leaving process intervals kk
$F^R_{i,kk}$	component flow after reaction
$Ctr_{k,kk}$	component flow after reaction
y_{kk}	selection of process intervals (binary)

strategic decisions at business level requires the knowledge of performance indicators for a given process, which are the end results of the design and optimization at the engineering level. As a consequence, the two layers need to be solved iteratively. A schematic representation of the required workflow is given in Fig. 1.

Moreover, because of the involved complexities, it is difficult to automate this procedure, and therefore, it is arguably not optimal for applications that require several successive solutions of the problem over the project lifetime; for example, because of variations in parameter values (i.e. prices in volatile markets) or in process knowledge and modeling (i.e. new technologies). For the same reason, the number of alternatives which can be evaluated is also limited.

Finally, analysis techniques such as sensitivity analysis and scenario planning are in general applied to each of the layers separately, and therefore are not able to capture the interdependencies between them.

For the above mentioned challenges, the development of systematic methods and computer aided tools (designed to manage the complexity of the problem supporting the simultaneous integrated solution of both problem layers) promises to benefit the industry by making extensive, transparent and updated information available to the decision makers at cost effective manner (less time and resources would be used to generate many alternatives and solutions relative to traditional sequential approach).

In this paper we present a framework for enterprise-wide synthesis and design of processing networks, integrating business and engineering issues. The increased complexity of the problem results from considering the synthesis and design of processing networks as open problems. Here, the problems are represented using a novel approach, which is based on a modified formulation of the transhipment problem integrated with a superstructure to consider non fixed topologies. The process network design/synthesis problem is cast as a Mixed Integer Non Linear Programming (MINLP) problem, and solved to determine simultaneously the optimal set of both the strategic decisions (represented by binary variables) and of the tactical decisions (represented by continuous variables). Excel is used for compiling the necessary input data for the solution of the MINLP problem, while GAMS is used for implementing and solving it.

The paper is organized in the following way: in the first part the methodology and modeling issues are presented—this consists of the problem statement, the framework and the software implementation issues. In the second part the developed framework together with the implemented methods and tools is applied to an industrial case study. The case study deals with the determination of the optimal processing network for the utilization of a resource (soybean). The flexibility of the tool is demonstrated by solving the case study for four different scenarios from the soybean oil processing industry.

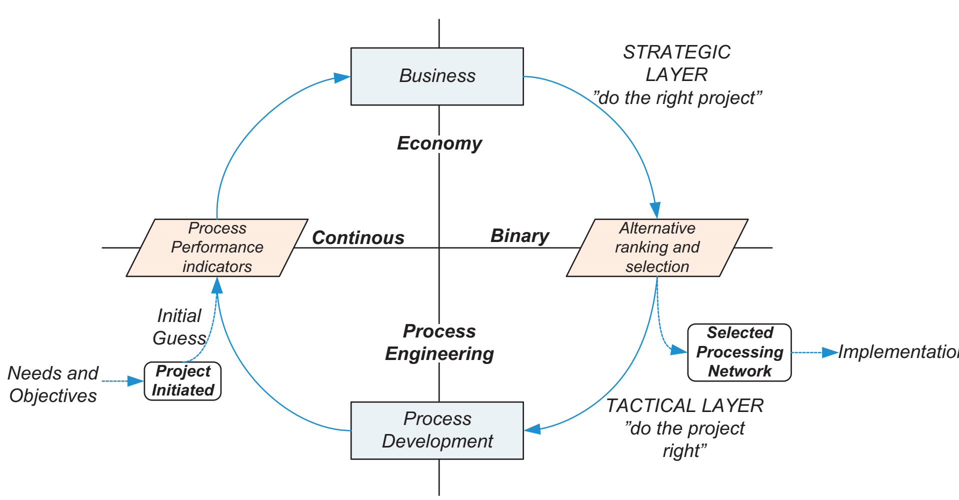

Fig. 1. Recursive workflow for business and engineering decisions—"do the right project, do the project right" decomposition.