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DECISION-MAKING FOR PETROCHEMICAL PLANNING USING MULTIOBJECTIVE AND STRATEGIC TOOLS

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Decision-making for planning a petrochemical industry is a difficult task, particularly when decisions are required to be made under constraints and different objectives. This paper presents the application of multiobjective optimization tools for planning of a mixed-integer model of a petrochemical industry to arrive at a small set of good solutions out of the Pareto optimal solutions. The two main objectives are economic gain and risk from plant accidents. Following this optimization, an economical strategic tool is used to reach the final decision. The proposed procedure has been applied to the petrochemical industry in Kuwait and found to be successful in defining a balanced petrochemical network with acceptable risk.

Keywords: petrochemical industry; multiobjective optimization; strategic tool; mixed integer programming.

INTRODUCTION

Decision-making is the heart of most important activities in businesses and governments. In today's competitive environment, continuous global operations and information management systems are essential tools to improve throughput, maximize yield, and resolve quality problems rapidly. Efficient data analysis and integration of analytical results into the decision-making process, are critical to maintain profitability, and to achieve world-class quality.

For all industries and especially for the petrochemical industry, decision-making generally involves comparing two or more risky options, with uncertainty being a major factor. Industry decision problems may be divided into three categories (Shah, 2005): (1) infrastructure (network) design; (2) policy formulation; (3) planning and scheduling. Following the profit-maximization principle does not always necessarily lead to the proper decision because safety, for instance, is another factor which has recently started to have a major and, indeed, decisive influence. The problem with regard to safety usually arises from the toxicity of chemicals which unavoidably accompany the production process. The raw material, the intermediate, and the finished products present the primary independent hazard element (Ward, 2002). The issue of controlling safety in the production of hazardous chemicals is by no means less important than that of controlling the economics of production. Ignoring this increasingly important factor would be a great oversight, since safety and protection of the environment are becoming major forces influencing the shape of the industry.

From the history of chemical accidents, the risk from deliberate acts or large chemical accidents are now considered both real and credible. The risks associated with such accidents must be estimated so that adequate countermeasures are provided that ensure that the risks are as low as reasonably practical. Therefore, good risk quantification, especially due to accidents, and continual improvement in safety planning has become a very important objective for the petrochemical industry. An objective that runs parallel to the economical gain from that industry. Many economical objectives were used in industry planning. Examples are: minimum cost (Fathi-Afshar and Rudd, 1981; De Santiago *et al.*, 1986; Bagajewicz and Cabrera, 2003); maximum profit (Song *et al.*, 2002; Bonfill *et al.*, 2004); maximum net present value (Rodera *et al.*, 2002). On the other hand, many safety or hazard indices were used for planning. Examples are: Tyler (1985); Edwards and Lawrence (1993). Tyler (1985) used the Mond index (ICI Mond Division, 1993) that highlights features of plant having a significant toxicity, fire and explosion hazard potential. Edwards and Lawrence (1993) developed an inherent safety index calculated as the sum of a chemical score and a process score. The chemical score consists of inventory, flammability as flash point and boiling point, explosiveness as a difference between explosion limits, and toxicity as the chemical threshold limit value (TLV). The process score includes temperature, pressure and yield.

The focus of the work described in this paper is to perform early planning and decision-making for a number of

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petrochemical plants producing desired chemicals. It is aimed at structuring these plants in a network for a maximum economical gain, with long-range economical insight, and for a minimum risk to people due to possible chemical accidents. The two objectives of economics and risk are combined in different forms generating many possible optimum solutions and the final decision is found using a strategic tool. This paper provides tools to support decision-making the most important of which is the incorporation of a new risk index into the objective and the visualization of the industry options on the portfolio of a strategic tool.

TOOLS FOR PETROCHEMICAL PLANNING

Economic Forecasting

Forecasting the future prices of petrochemicals represents a major input to all aspects of production and market planning in the petrochemical industry. The two classes of forecasting techniques are qualitative, which use either experts, salespeople, or customers to make forecasts, and quantitative, most of which use historic data to make the forecasts. An important quantitative forecasting category is causal models.

Causal models, relate statistically the time-series of interest (dependent variable) to one or more other time-series (independent variables) over the same time period if there appears to be a logical cause for this correlation, then a statistical model describing this relationship can be constructed. Knowing the value of the correlated variable (independent variable), the model is used to forecast the dependent variable. The most applied causal model is the regression model. This approach attempts to quantitatively relate a chemical demand (dependent variable), for instance, to the causal forces (independent variables), which determine the chemical demand. Thus regression is a mathematical procedure that takes into account the relationship of the dependent variable and the independent variable(s).

To illustrate this point, one can assume that the demand of a chemical is a function of the Gross Domestic Product (GDP), chemical price and oil price. All three independent variables are assumed to be exogenously determined; they are not influenced by the level of demand itself or by each other.

Forms of models that can be used as causal models are transfer functions. Second Order Plus Dead Time (SOPDT) transfer function model is used extensively in system identification and it can be used as a forecasting model. The model has the form:

$$\frac{\text{dependent variable}}{\text{independent variable}} = \frac{ke^{-\theta s}}{\tau^2 s^2 + 2\zeta\tau s + 1} \tag{1}$$

where k is the gain, θ is the dead time (delay), s is the Laplace transform variable, τ is the time constant and ζ is the damping factor.

Another useful model, used extensively in forecasting, is the polynomial form of a transfer function. It is explicitly defined as a polynomial between the input u (independent variable) and the output y (dependent variable). The current output $y(t)$ (dependent variable) is a function of previous na outputs and previous nb inputs delayed by nk together with some noise $e(t)$. The model is named Auto-Regression with eXogenous variable (ARX) model (Ljung, 1999) and is presented as:

$$\begin{aligned} y(t) + a_1 y(t-1) + \cdots + a_{\mathrm{na}} y(t-na) \\ = b_1 u(t-nk) + b_2 u(t-nk-1) + \cdots \\ + b_{\mathrm{nb}} u(t-nk-nb) + e(t) \end{aligned} \tag{2}$$

Nogales *et al.* (2002) used ARX and a transfer function causal model to forecast the next-day electricity prices. They used the electricity demand as the independent variable. Al-Sharrah *et al.* (2003), also, used SOPDT and ARX models to forecast chemical prices using oil price as the independent variable.

Chemical Accidents Risk

Over the last few decades, the petrochemical industry has reduced its harmful emissions significantly, amongst others via environmental management and technological development (Dijkema *et al.*, 2003). Health, Safety and Environment (HSE) issues are a concern for all industries, but particularly for the petrochemical industry. The consumers, employees, shareholders, legislators and the communities for which the industry operates are all becoming increasingly aware of HSE issues and demand ever-higher standards.

The risk from an industrial process or a technical installation is defined, in the process industries, as the combination of an incident probability and the magnitude of its harmful effects. Thus, this term strongly refers to probabilistic assessment. Risk analysis on a theoretical basis with a full-scope analysis is difficult for the chemical industry. The variety of chemical installations would require too much effort for such a procedure (Hille, 2002). Nevertheless, the question remains as to whether procedures of risk evaluations are available that are not so comprehensive, much easier to apply and yield useful results for risk comparisons.

Recently developed and applied risk analysis tools are optimal risk analysis (ORA) proposed by Khan and Abbasi (1998, 2001) and 'risk curve' introduced by Cuny and Lejeune (2003). ORA involves four steps: (1) hazard identification and screening, (2) hazard assessment (both qualitative and quantitative), (3) quantification of hazards or consequence analysis, and (4) risk estimation. The 'risk curve' results from the combination of the two dimensions of quantitative risk assessment: frequency and severity.

A simple risk index

Starting from the basic definition of risk, which was the product of the incident probability and the magnitude of the harmful effects, the simple accidents risk index K (Al-Sharrah *et al.*, 2006) is used. It is an index that can be applied to chemical plants using the properties of the major chemicals associated with production. The index is:

$$K = Freq \times Haz \times Inv \times Size \tag{3}$$

where $Freq$ = frequency of accidents, number of accidents per process per year, Haz = hazardous effect of a chemical, people affected per tonne of chemical released,

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