SIMULTANEOUS ENVIRONMENTAL AND FINANCIAL RISK MANAGEMENT IN THE DECISION MAKING ASSOCIATED TO PROCESS DESIGN

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EXTENDED ABSTRACT

In this paper, we propose a new procedure to handle financial and environmental risk simultaneously. For this we propose a new measure of environmental risk, which is and extension of existing financial risk measures. We propose to use a risk surface as a generalization of the known one-dimensional risk representation through cumulative probabilities and we show how different risks can be handled with this scheme. As an example, we use a catalytic reforming unit in this paper, but we also made a similar study for a Vinyl Chloride plant, which we will show in the presentation.

In recent years, environmental considerations have been added as constraints and sometimes also used as an objective in process design (Mallick et al, 1996; Chang and Hwang, 1996; Lim et. Al., 1999; Dantus and High, 1999; Yang and Shi, 2000; Alexander et al., 2000; Chen et al., 2002; Allen and Shonnard, 2002; Chakraborty and Linninger, 2002, 2003). The new approach is one of treating the problem as a multiobjective one: minimizing environmental impact and maximizing profit, leading to Pareto optimal representations. Some of the indicators used to assess environmental impact are: *life cycle analysis*, the *sustainable process index* and, the *environmental impact index* of each chemical. Dantus & High (1999) presented a two-objective (profit and environmental impact) optimization approach under uncertainty. They use a stochastic optimization framework, based on programming, simulations and a simulated annealing scheme. Throughput changes as well as a time horizon were not considered. In turn, Chakraborty and Linninger (2002a,b) studied the problem of waste management in pharmaceutical industries where they constricted Pareto optimal diagrams including total cost and an environmental index. They also build a straight stochastic model to determine optimal decision making under uncertainty.

Although uncertainty was taken into account in the above work, environmental risks were not considered. Moreover, the interaction between these and financial risks was not discussed. This is the main goal of this manuscript.

The problem can be posed as multicriteria optimization problem as follows:

$$\left.\begin{array}{l} \text{Minimize } \{\textit{Expected Cost, Expected Environmental Impact Indices, } \textbf{\textit{Risks (both)}}\} \\ \quad \text{s.t} \\ \qquad \textit{Material and Energy balances} \\ \qquad \textit{Property calculation equations} \\ \qquad \textit{Equipment design equations} \end{array}\right\} \quad (2)$$

Without the use of risk, this is the formulation suggested by Dantus and High (1999) and others.

Risk is defined differently by many authors. For stock portfolio optimization, financial risk is associated to volatility of the profit distribution through a variety of metrics, such as standard deviation or Value at Risk (VaR). In engineering, risk is characterized by cumulative probability distribution of profit or through measures like downside risk (Eppen et al., 1989). Recently, Barbaro and Bagajewicz (2003, 2004) posed the risk management problem in the framework of two-stage stochastic programming and proposed a multiobjective methodology to obtain less risky (albeit less profitable) design options.

In turn, environmental risk has been defined differently. The 1997 US Presidential/Congressional Commission on Risk Assessment & Risk Management. Environmental risk is thus defined as "the probability that a substance or a situation will produce harm under specific conditions." The definition goes on to add: "Risk is a combination of two factors: the probability that an adverse event will occur and the consequences of the adverse event." We introduce an alternative definition of risk.

Formally, we define risk as the probability that the profit (or any other utility function) of a design venture x will be lower than a certain target value Ω (Barbaro and Bagajewicz, 2004):

$$FRisk(x,\Omega) = \mathrm{P}\{Profit(x) \leq \Omega\} \qquad (1)$$

This corresponds to a cumulative distribution of profit, which is illustrated in figure 1.

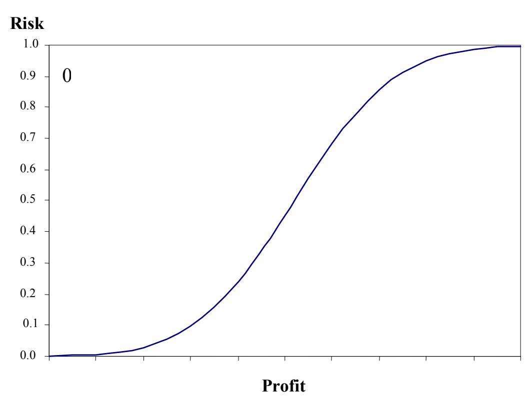

Figure 1. Definition of Risk

We here enlarge the scope of the definition adopted by congress and we propose that risk be defined as the probability of a certain design/venture to produce an environmental impact larger than a certain targeted limit. That is, for a given design/venture x, the environmental risk is given by:

$$ERisk(x,\Theta) = \mathrm{P}\{\theta(x) > \Theta\} \quad (2)$$

where θ is the environmental impact and Θ is the environmental impact aspiration level (minimum impact desired). We therefore propose the use of curves like those of Figure 1, with the abscissa being environmental impact instead of profit. Thus, the main proposed methodology is to assess a level of environmental impact and associate a probability to it. We propose to take this one step further: We recognize that there are many uncertainties that the plant is subject throughout its life time like, product demands in each year, deteriorating equipment that affect performance or efficiency, and other economic conditions that influence an operation. One example of the latter would be the usual decision of recycling by-products to the feed of the process when their prices go down (Table 1).

Table 1. Uncertainties (from Dantus and High, 1999)

Type	Example
Process model uncertainty	Kinetic constants, physical properties, transfer coefficients
Process uncertainty	Flow rate and temperature variations, stream quality.
Economic model and environmental impact	Capital costs, manufacturing costs, direct costs, release factors, hazard values, liability cost and less tangible costs
External uncertainty	Product demand, prices, feed stream availability, feed composition
Discrete uncertainty	Equipment availability and other discrete random events
Regulatory uncertainty	Modified emission standards, and new environment regulations
Time uncertainty	Investment delays (i.e. the project might have a better performance in the future)

Based on this, we divide the decisions in two sets: first stage (here and now, decisions) and second stage, as in two stage stochastic programming. Thus, first stage decisions are the usual design parameters: flowsheet structure, equipment sizes, utilities capabilities, etc. The second stage decisions are mainly operational: plant throughput, recycling of by-products, product qualities, maintenance actions, etc. These are a function of the actual product demand and the efficiency of the equipment, which as said, can deteriorate through time. Decisions such as plant expansions are sometimes treated as first stage or sometimes considered second stage decision, or since they are structural, formally part of multi-stage models. Since the reduction of environmental impact is conflicting with profit most of the time, the two need to be managed.

Catalytic reforming process

Catalytic reforming is a process for improving the octane quality of straight-run naphtha. The main reaction is dehydrogenation of naphthenes to aromatics, which are high in octane value. The plant was simulated for a variety of conditions using the PROII simulator (Simsci). To find the overall environmental impact, the amount of carbon dioxide and benzene are combined to represent the impact for each design. In this work, benzene was valued to have 3.5 times larger impact than carbon dioxide, due to higher concern in the carcinogenic hazardous effect. The reactor temperature is indicator of severity. Higher severity means lower reformate yield but higher quality of reformate (lower octane number). Besides, the cracked hydrocarbons amount increases at high severity. Also at higher temperatures, the level of aromatics is higher. The benzene produced was calculated by means of kinetic reaction model and finally, the CO_2 release was obtained from furnace duty. We chose one capacity (20 kbd) and two reactor temperatures (495°C and 501 °C) as basic designs. This results in four alternatives (high/low temperature and pinch/practical heat recovery). The costs for the 4 basic designs were scaled up for other capacities (20 and 26 kbd) using a scaling factor of 0.6. These capacities were carefully chosen after studying the projected gasoline demand and naphtha supply data. We considered uncertainties in reformate demand and product prices. Table 2 shows some results.

Table 2. Expected profits and expected environmental impacts.

Plant Capacity	Type of design	Profit (Million $)	Environmental impact (kg/hr)
14	a	37.2	11,343
	b	40.2	11,550
	c	34.4	11,483
	d	36.0	11,763
20	a	37.7	14,223
	b	40.5	14,481
	c	34.4	14,398
	d	35.5	14,748
26	a	22.0	15,994
	b	24.3	16,284
	c	18.4	16,190
	d	18.9	16,584

Generally, the decision maker, an investor, would favor the design with high profit/low environmental impact. Both the 14 and the 20 kbd capacity plants can make more satisfactory profits than the 26 kbd capacity plant, especially the 3 designs 26a and 26c-d should be avoided due to, relatively, low profit and high EI values. Moreover, they have smaller environmental impact. Because the 14 kbd design has similar profit and smaller EI, one would choose this one. We combined all risk curves in one single three dimension curve in Figure 2. From these curves, one can assess the various risks, and this will be illustrated in the presentation.

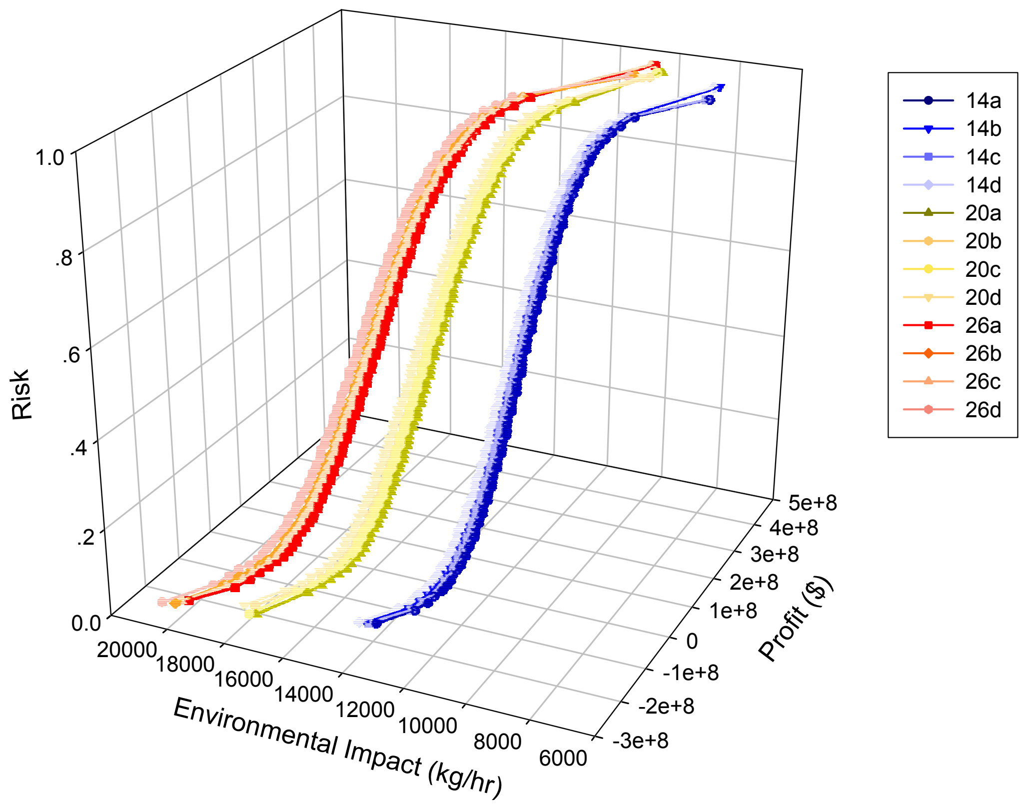

Figure 9. Three dimensional risk curves (Catalytic Reforming).

CONCLUSIONS

We show here that environmental risk can be treated through a new concept. In the presentation, we will illustrate methodologies that lead to a decision making associated with the different attitudes one may have towards risk.

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