Modelling Long-Term Decisions to Limit Effects of Market Uncertainties

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This paper proposes an alternative approach to handle uncertainties for both the plant-wide and the enterprise-wide optimization problems. Such an approach deals with the introduction of long-term policies and business strategies (*e.g.* tight supply contracts, take-or-pay agreements) into the classical supply chain problem. Contracts and agreements have more and more the task to reduce the effects of market demand and price volatilities and their integration in the typical mixed-integer models for supply chain optimization takes to reliable enterprise scheduling and planning. Technique validation and numerical comparison against *status quo* are proposed and discussed.

1. Introduction

An open issue in the supply chain management is the handling of uncertainties. The most common sources for uncertainty generally consists of unidentifiable disturbances, model parameters, bullwhip effect, and corrective actions; in addition, scheduling and planning optimization problems are strongly affected by some other specific issues especially dealing with the market volatility, instability of raw materials and energy costs, end-product prices and market demand peaks fluctuations to quote a few.

On this subject, several methodologies are proposed in the literature aiming at the mixed-integer optimization under uncertainties. Some of them propose a stochastic approach to address this challenge, modeling the probability related to some specific parameters; conversely, some others propose a multi-scenarios approach where some cases defined *a priori* has a certain possibility to happen.

This paper proposes an alternative approach to face the problem of uncertainties. It exploits the business strategies adopted by large-scale and/or energy-intensive enterprises in the definition of long-term policies for the energy and raw material supplies, basing on the idea of integrating tight supply contracts and sale and purchase agreements into the mixed-integer optimization through the Boolean logic (Park *et al.*, 2006; Manenti and Manca, 2008). By doing so, long-term policies allow plan and schedule plant production and units operation in a more reliable way. The most important business strategies adopted in large-scale industrial processes are discussed and modeled by using both continuous and discrete variables. A numerical comparison with the classical supply chain optimization is proposed on an industrial plant for industrial gases production.

2. Hierarchies in the Supply or “Value” Chain

Supply chain traditionally means optimizing the overall production chain, which is characterized by a stiff horizontal hierarchy with the aim to transform raw materials into final products through a series of processes, treatments, units, and operations, as exhaustively discussed in the scientific literature (Stevens, 1989; Towill, 1991). This definition of supply chain is the directly consequence of the classical approach, which has the lack of considering the tactical optimization problem only. In other words, the supply chain focuses the attention on problematic issues that are strictly related to the plant and to the information coming from the field. More and more frequently, a vertical hierarchy supports the aforementioned approach (Manenti and Rovaglio, 2008). This second hierarchy complies with the process control structure and includes all the optimal control levels. Starting from the lowest level, there is the (i) conventional control, together with measurements, sensors, and control loops; (ii) advanced predictive control based on nonlinear, first-principles mathematical models; (iii) dynamic optimization for economic objectives and real time applications; (iv) scheduling and (v) planning, both related to the operational optimization of production sites; (vi) shared (or corporation) planning, which allows optimizing complex production and distribution networks. The integration between these optimal control levels is an open issue of process system engineering and computer-aided process engineering communities. Although both the abovementioned hierarchies are considered in the solution of a generic supply chain problem, such as a production scheduling or planning, the result may be sometimes inadequate or even economically disadvantageous, especially for the difficulties to handle market uncertainties, demand fluctuations, price volatilities, *etc.*. The definition of adequate medium- and long-term trade agreements among raw materials and energy suppliers, primary industries, manufacturers, and retailers allows overcoming the myopic vision of the classical approach, which does not consider any commercial interaction, as well as it allows facing the uncertainty issue, at least partially (Manenti, 2008). In order to clarify this concept, the following section is dedicated to the modelling of some of the most widespread clauses.

3. Relevant Trade Agreements

Large-scale societies, characterized by decentralized production (multi-site) and a branched network for final distribution, are used to sign strategic sales and purchasing agreements together with both the electric energy and raw materials suppliers (upstream) as well as with final customers (end-users or subordinated societies), in order to ensure *a priori* a relevant portion of the net present value and to fix future price and cost of final products and raw materials/energy, respectively. According to Ydstie (Ydstie, 2004), it is preferable to replace the net operating margin index with the net present value index. In other words, each society has the interest to sell a portion of the future production and to buy *a priori* a certain amount of raw materials and/or power supply. A similar approach is often adopted by primary (energy intensive) industries, which are the main clients of national energy suppliers. This is above all dictated by the well-known trend in the national energetic requirement of the industrialized countries (for more details, refer to National electric energy suppliers, *i.e.* www.terna.it), which is characterized by several fluctuations:

- financial and market volatilities (minutes);
- high energy demand daytime and low demand at the night;
- reduced energy consumption during weekends and holidays periods;
- seasonal variations (summer/winter).

As an example, focusing on the daily fluctuations, the national electric energy supplier may have the need of interrupting the power supply to the main energy-intensive users when the demand is close to the highest peaks, specifically at 9-12am and 15-17pm. The interruption has to be carried out in due time to prevent possible energy blackouts. This is possible since the energy supplier adopt predictive techniques and on-line tools in order to monitor continuously the performances and to estimate the future trend of the National energy demand: the energy demand is updated every 15 minutes on both the short- and the medium-time scales. Especially for this reason, some primary industries offer a particular service, the so-called *Blackout Clause*, to the energy supplier.

4. Boolean Logic for Modelling Strategy Business

The aim of the present research activity is to give a methodology in order to introduce some specific and complex clauses defined in energy supply contracts and trade agreements in general, which allow obtaining a nearer-optimal solution than that one obtained by the classical supply chain approach. In this perspective, two of the most common business strategies, such as *Blackout Clause* and *Take or Pay* contracts, are discussed and modelled making use of both discrete and continuous variable, in order to develop a mathematical model that allows solving the multifaceted decision-making problem, which scheduling and planning issues are based on.

4.1. Blackout Clause

The Blackout Clause is a service that some energy intensive industries offer to the National supplier. In fact, the National supplier asks the opportunity to temporarily interrupt the power supply at any time with either a short warning or without any advice. In exchange to the *Blackout Clause* offered by the primary industries, the National supplier recognizes a relatively large discount in the monthly energetic bill of the single production site. Actually, the discount is granted only if particular conditions are respected: for instance, by guaranteeing a minimum monthly consumption of electric energy, called *Blackout Threshold*.

The system is even more complex since every production site signs a customized supply contract with national supplier, by involving costs and conditions that significantly influence the enterprise-wide production planning and the end-product distribution. In the following equations, *BlackoutClause* is the Boolean variable describing the possibility to achieve the price cut in the overall electric energy cost. The energy consumption on the discretized time horizon (NP) is evaluated as follows:

$$ee\_BlackoutClause = \sum_{t=1}^{NP}\left(ee\_ProcessUnits + ee\_Utilities_t\right) \tag{1}$$

where *t* is the single sampling time and prefix *ee_* denotes the electric energy consumption. Therefore, as defined by contract, the electrical consumption does account for neither the programmed and failure maintenance periods *h_maint* (equation 2), nor for possible *Blackout Clause* shut-downs. *BlackoutClause_eff* is the effective monthly power consumption of each single site of primary industries:

$$BlackoutClause\_eff = \left(\frac{ee\_BlackoutClause}{(NP - h\_maint \,/\, h\_period)} \right) \Big/ h\_period \tag{2}$$

This parameter is multiplied by a minimum tolerance factor *SelectedTolerance* and compared to the consumption limit *P_BlackoutClause*, which is given *a priori*:

$$Ratio\_BlackoutClause = \frac{BlackoutClause\_eff}{SelectedTolerance \cdot P\_BlackoutClause} \tag{3}$$

The consumption limit is similar to the *Blackout Threshold*. Note that the discount is granted only if *Ratio_BlackoutClause* is not lower than one:

$$BlackoutClause \le Ratio\_BlackoutClause \tag{4}$$

Inequality constraint (4) is the necessary but not sufficient condition to achieve the *Blackout Clause* discount. Actually, it may sometimes happen that other scenarios with reduced productions (and not contemplating any discount) are economically more attractive on the specific time horizon. In this case, the Boolean variable *BlackoutClause* is kept null even if the *Ratio_BlackoutClause* value is greater than one.

4.2. Take or Pay (or Minimum-Bill) Agreements

A *Take or Pay* contract is a mixture of (i) requirements contract and (ii) indefinite quantity contracts (Dobler *et al.*, 1984). A requirements contract provides for the purchase from a supplier for a specific operation or activity. In order to be legal, it should provide for a minimum quantity (or a specific range in which) the buyer is committed to take. An indefinite quantity contract provides for the delivery of materials in indefinite quantities and times. In this case, the buyer is obligated to purchase between designated high and low quantity limits. *Take or Pay* clauses, i.e. sale and purchase clauses, are generally offered to manufacturing societies by primary industries. Aiming at a reduction in the primary product price, the manufacturing industry assures to buy a minimum amount of goods from the primary industry for a specified period and, in case of reduced purchase, guarantees the minimum established payment. In this case, the solution of a nested supply chain problem must be accounted for, since the business-wide optimization can evaluate the optimal goods amount for each manufacturing process, whereas the enterprise-wide algorithm investigates the best *Take or Pay* proposal. The binary variable *X_TOP* is defined as follows:

$$X\_TOP_t \begin{cases} 1, \; if \; \left(ManufacturingSample < MinimumLimit \right) \\ 0, \; otherwise \end{cases} \tag{5}$$

It assumes a value of 1 if the goods amount is smaller than the assigned minimum one. By considering the following generic objective function:

$$Profit = \sum_{t=1}^{NP} (Revenues_t - Costs_t) \tag{6}$$

enterprise-wide revenues, simplified for a single manufacturing site (equation 7), correspond to the minimum negotiated payment if the manufacturing client requires a reduced amount of goods, otherwise effective supplies are considered in the evaluation of the overall profit.

$$Revenues = \sum_{t=1}^{NP}\sum_{y=1}^{NPD}\left[SalesPrice_y \cdot (ManufNeeds_t \cdot (1 - X\_TOP_t) + Limit\_TOP \cdot X\_TOP_t\right] \quad (7)$$

where *y* index represents the commodities produced by primary industries.

5. Application and Numerical Comparison

An air separation unit, which belongs to the enterprise-wide mathematical model already discussed elsewhere (Manenti and Rovaglio, 2009; Manenti and Manca, 2009), is adopted as a case study. It consists of a medium-scale mixed-integer linear programming that involves about 6000 variables. The mathematical solver adopted is CoinCBC, which belongs to GAMS package (Brooke *et al.*, 2004). The solution requires no more than 2 hours using a Pentium IV, 2.6 GHz, 2 GB of RAM, OS Windows 2003. By adopting the typical market demand of the liquid oxygen that is reported in Figure 1, the product requirements are positive daytime and null during the night, the whole Sunday, and also throughout the holiday periods. This is in strong conflict with the power costs. Actually, it is worth noting that the electric energy cost is higher daytime, when the power request is large, and reduced during the night and the weekend, when the power request is significantly small. This inevitably leads to the saw-tooth trend of liquid product holdups (Figure 2), which are continuously increased during the night and decreased daytime. The effects of tight supply contracts are shown in Figure 2, which provides the comparison between conventional operational planning for the liquid oxygen storage and the operational planning defined by the supply chain problem that includes the *Blackout Clause*. Whereas the first two weeks are characterized by overlapped trends, in the remaining weeks a clear gap can be observed. In fact, the additional constraints of *Blackout Clause* induce the air separation unit to store more LOX than the conventional planning. Moreover, in the conventional operational planning, the plant is off throughout the last two days, so to avoid overproductions in final product as well as reduce the operating costs and keep low levels in liquid storages, since cryogenic holdups are associated to elevated costs. As a consequence, a minimum stored volume is expected at the end of the simulation time. Conversely, by introducing constraints due to power supply contract, a LOX overproduction is planned during the last two days, apparently against the basic principles of supply chain management. Actually, by means of final overproduction, the Blackout Threshold is reached at the 29th day of the month, with a consequent large discount in the energetic bill.

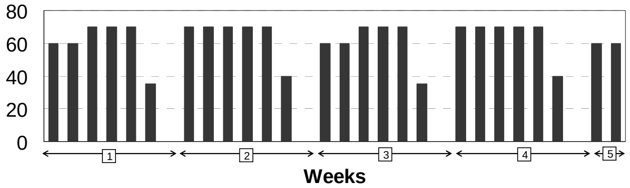

Figure 1. Typical monthly market demand (% of plant capacity) of the liquid oxygen.

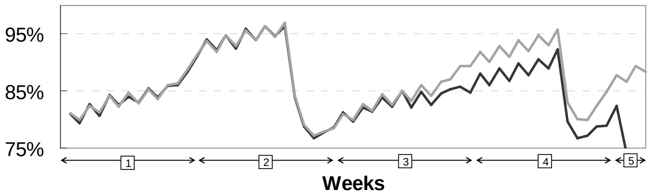

Figure 2. Monthly planning for the cryogenic storage of liquid oxygen: classical supply chain (grey line) versus the proposed approach.

6. Conclusions

This paper is aimed at the introduction of commercial constraints (supply contracts and trade agreements) in the multifaceted problem of handling uncertainties in the enterprise-wide optimization. By doing so, the monthly planning of the selected case study is moved towards a nearer-optimal solution, accounting for economic penalties and stiffer price and costs fluctuations. The introduction of such constraints allows increasing, sometimes significantly, the net operating margin.

7. References

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