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Operational Planning of Crude Oil Processing Terminals

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Abstract
A typical crude oil supply chain consists of production oilfields, processing terminals, storage facilities and refineries, interconnected by means of pipelines. In processing terminals, different varieties of base crude-oils are received, processed and blended in order to produce commercial varieties which are exported and/or sent to refineries. In the last decade, very few contributions have addressed the operational planning of processing terminals. In this work, an operational planning scheme, which realistically addresses the typical operation of such processes in the context of crude oil supply chains, is proposed.

Keywords: Operational planning, Processing terminals, Blending processes, Global optimization

1. Introduction

Within any process industry, from a planning view point it is possible to identify several instances of decision making which can be hierarchically classified as "supply chain tactical planning", "process operational planning" and "process control" (Shapiro, 2001). Tactical planning seeks to coordinate the operation of the nodes that conform the supply chain, while operational planning focuses on the detailed operation of each node taking into consideration the tactical planning level decisions.
Tactical and operational planning of crude oil supply chains have been largely addressed in the last decade due to the considerable potential economic benefits from improving the whole business operation (Kelly and Mann, 2003). At the tactical level, the petroleum supply chain has been modelled and optimized using different approaches (e.g. Neiro and Pinto, 2004 and Aires et al., 2004). At an operational level, several instances of the supply chain have motivated academic and industrial contributions. This is the case of the short term scheduling of refinery operations due to the economic impact of such systems within the supply chain (e.g. Chandra Reddy et al., 2004). Oilfield production planning and scheduling have also received considerable attention (e.g. Ortiz-Gomez et al., 2001). However, to the best of our knowledge, no

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contributions regarding the detailed operational planning of Processing Terminals (PTs) have been published in the open literature. PTs are key instances within petroleum supply chains. In PTs, different base crude oils are received, processed in order to adjust their quality parameters (water, salt, sulphur contents, etc.) and blended in adequate proportions to produce commercial crude oil varieties for local refineries and overseas trade.

In this article, an operational planning scheme is proposed, which realistically addresses the operations of PTs within petroleum supply chains. The proposed scheme, which consist of a blending optimization model and an inventories simulator, is designed to be part of a “Control and Management System” of crude oil blending processes. The considered blending optimization model is inherently nonlinear due to the bilinear terms arising in the mass balances (Quesada and Grossmann, 1995) and in this work it is solved to global optimality with “state of the art” global optimization solvers.

This article is structured as follows. In Section 2 the operations of a typical PT in the context of the petroleum supply chain of a large oil company is described as well as the information flow between the tactical and operational planning levels. In Section 3 the proposed operational planning scheme that addresses both, the “processing and blending section” and the “storage and crude oil transfer section” of the PT is presented. The detailed mathematical programming model for the “processing and blending section” is described in Section 4 and its performance is illustrated by means of a real study case. Section 5 closes the article with some conclusions.

2. General description of PT operations

Consider the petroleum supply chain of a large oil company roughly depicted in Figure 1. Its relevant components are production oilfields (both on and offshore) which feed PTs through pipelines. In PTs the different base crude oils are received, processed and blended, and the produced commercial varieties pumped to refineries and/or exported to the overseas market through tankers.

The principal process in PTs is the blending of base crude oils of different qualities, in order to produce blends that meet contractual quality specifications. Important crude oil quality parameters are density, salt, water and sulphur contents among others. The main objective of PTs´ operations is to maximize the contribution of low quality crude oils (heavy, high sulphur content oils) to the blends.

Previous to the blending, crude oils are stabilized, dehydrated and desalinated in appropriate equipment in order to adjust their volatiles, water and salt contents to quality specifications. The blending is performed in blending nodes, in which low quality oils are injected to higher quality oil streams. Different types of commercial varieties can be produced in this way through different blending arrangements. The produced commercial varieties are allocated to local refineries through pipelines and transferred to tankers for international trade.

PTs are required to process all the crude oil produced in oilfields. In other words, they must not constraint the income crude oil flow-rates. This is usually feasible since crude oil is continuously leaving the system to refineries and through tankers. However, it may happen that due to unfavourable climatic conditions, crude oil can not be uploaded to tankers and starts to accumulate in the system. A programmed shut down of production oilfields is usually implemented if the storage capacity of the PT is about to be exceeded.

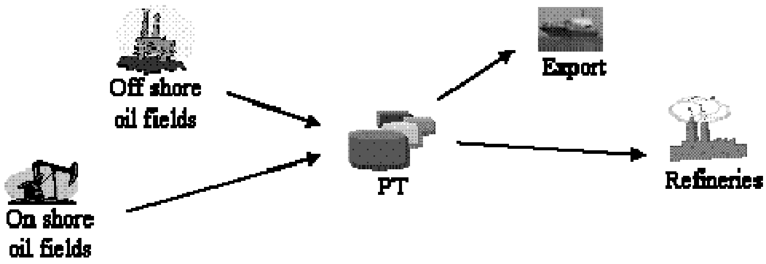


Figure 1. Typical crude oil supply chain

From a logistics point of view, the operations of PTs are tightly restrained to the tactical planning decisions taken at the supply chain management level. In this sense, PTs periodically receive the required amounts of the different crude oils to be sent to refineries. In the PTs, the adequate proportions of the different crude oils are implemented in the blending nodes to meet the specified refinery flow-rates. The remaining crude oil is sent to tanks where the different varieties are stored to attend international commitments. PTs periodically communicate the availability of crude oil to the tactical management level which decides "on spot" crude oil sales or establishes longer term contractual obligations.
According to the above description it is concluded that a realistic operational planning scheme for a PT should address the following aspects:

- Accomplish production levels for refinery provision in terms of quantity and quality
- Accomplish quality levels for export crude oils
- Maximize the contribution of low quality crude oils to the blends
- Monitor crude oil inventories

In the following section an operational planning scheme that fulfils the above requirements is presented.

3. Proposed operational planning scheme

As mentioned in the previous section, the operational planning level at the PT daily receives the amounts of the different oils varieties that have to be sent to refineries. Each week, the PT is also informed of the daily program for uploading batches of export oils (type and volume) to tankers.
Regarding flow-rates and quality parameters of the crude oil streams entering the system, periodic measurements are performed in several points of the supply chain and made available at the information systems of the company.
In order to design a tool that explicitly considers such an operative context and realistically adapts to the needs of the PT´s operators, a planning scheme is proposed whose information flow structure is depicted in Figure 2.

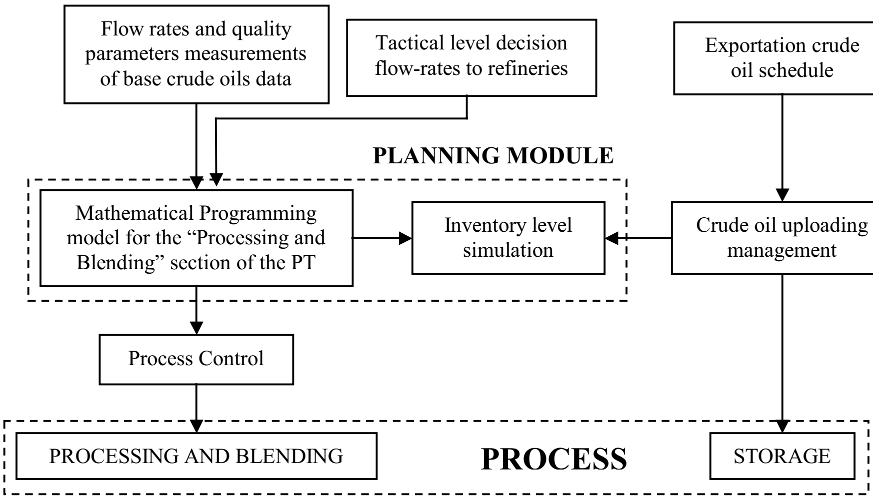


Figure 2. Planning Scheme of the PT

The general philosophy consists in splitting the planning module in two sections:

1. A mathematical programming model to optimize the blending process
2. A dynamic simulation system for inventory levels prediction

Because of the high degree of uncertainty in quality parameters and flow-rates of the crude oils entering the PT, and the fact that the outputs of the systems (flow-rates to refineries) are fixed by the tactical planning level, a "snap-shot" optimization model is considered as adequate for the operational planning of the process. The model is intended to be run each time the operating scenario significantly changes in terms of entering crude oil parameters (quantity and quality) and tactical decisions about flow-rates to refineries. Such information is fed to the model from the company's information systems (Figure 2). A detailed description of the model is presented in Section 4. The resulting "blending plan" is downloaded to the "process control" module to be implemented at process level (Figure 2).
In order to continuously predict the evolution of export crude oil inventories in storage tanks, a simulation tool is also proposed. Simulation results provide to the transfer operation manager a criterion when to start the crude oil transfer process to the tankers within the assigned "time window", according to maximum and minimum safety inventory levels. In case of unfavourable climatic conditions impeding the uploading process, simulation results can predict storage capacity saturation. The "simulation module" is fed from the "blending optimization module" and from the "crude oil uploading management module" as shown in Figure 2.

4. Mathematical model of the blending section

PTs are mainly arrangements of crude oil processing equipment, stream splitters and blending nodes. Processing equipment consist in stabilizers, where gas is removed from the oil, and dehydrators, where water is separated by gravity. Crude/water emulsions are also broken in dehydrators by means of chemicals promoters. The desalination process also occurs at the dehydrator since the water leaving the unit contains a large part of the salts originally present in the oil phase. Once the base crude oils are set up regarding volatiles, salt and water contents, they are blended in adequate proportions in the blending nodes.

The main purpose of PTs is to produce blends with the largest amount of low quality oil as possible while meeting contractual quality specifications. In the following, a general model for the processing and blending section of a PT is presented.

$$p_{i,st}^{O} = P_{i,st}(p_{i,st}^{I}, \boldsymbol{\theta}_{st}),\ \forall i \in \Omega I,\ \forall st \in \Omega ST \tag{1}$$

$$p_{i,d}^{O} = P_{i,d}(p_{i,d}^{I}, \boldsymbol{\theta}_{d}),\ \forall i \in \Omega I,\ \forall d \in \Omega D \tag{2}$$

$$p_{i,b}^{I_1} C_b^{I_1} + p_{i,b}^{I_2} C_b^{I_2} = p_{i,b}^{O} C_b^{O},\ \forall i \in \Omega I,\ \forall b \in \Omega B \tag{3}$$

$$p_{i,s}^{I} C_s^{I} = p_{i,s}^{O_1} C_s^{O_1} + p_{i,s}^{O_2} C_s^{O_2},\ \forall i \in \Omega I,\ \forall s \in \Omega S \tag{4}$$

$$C_j \geq C_j^{D},\ \forall j \in \Omega J \tag{5}$$

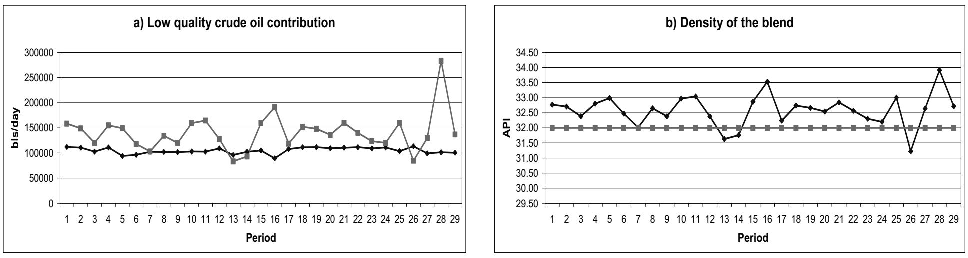
$$p_{i,j} \leq p_{i,j}^{D},\ \forall i \in \Omega I,\ \forall j \in \Omega J \tag{6}$$

where p denotes a general property and C a general stream, both in appropriate SI units. ΩI represents the set of quality parameters: density, water content, salt content and sulphur content. ΩST, ΩD, ΩB and ΩS represent the sets of stabilizers, dehydrators, blending nodes and splitters respectively. Super indices I, $I_{1,2}$ and O, $O_{1,2}$ denote input and output streams respectively. Process units are modelled as input-output relations in terms of the relevant quality parameters (eqs. 1 and 2). P(.) denotes a function which models the operation of each particular unit. $\boldsymbol{\theta}$ represents the operating parameters vector of each unit. Splitters as well as blending nodes are modelled through the corresponding mass balances (eqs. 3 and 4). Eqs. 5 and 6 stand as production and quality constraints on output streams (set ΩJ). Super index D denotes desired value. The considered objective function to be maximized is the "blending benefit": $\Phi = \sum_r C_r \Delta\$_r,\ r \in \Omega R$. Set ΩR represents the streams of low quality crude oils which are fed to higher quality crude oil streams and $\Delta\$_r$ is the difference of price between both crude oils.

The proposed model was applied to an existing PT which receives three base crude oils of high, medium and low qualities, regarding density and sulphur content. It produces five commercial varieties (two for refineries and three for export). The plant possesses one dehydrator, two stabilizers, nine blending nodes, six stream splitters and several storage tanks for the export oil.

The resulting model consists of 148 constraints and 172 optimization variables. It was programmed in GAMS (Brooke et al., 2003) and solved to global optimality with the global optimization solver BARON (Sahinidis and Tawarmalani, 2003).

In order to illustrate the benefits of the proposed approach, comparison of planning results with historical operating data for a single node is presented in Figure 3. As can be concluded from the graphics, the advantage of the blend planning is twofold: first, substantial increments up to 20% can be achieved regarding low quality crude oil contribution to the blend (Figure 3 a); second, the downstream variability in crude oil quality is minimized by producing crude oils in tight contractual quality specifications, which positively impacts in refinery operations (Figure 3 b).



▲ Historic data ■ Planning

Figure 3: Historic vs. Planned Operation

5. Conclusions

The proposed operational planning scheme for PTs realistically addresses the operations of such systems from a planning standpoint. A major advantage of such a scheme is the optimization of the blending process, which has a meaningful economic benefit since quality giveaway is minimized. Furthermore, the reduction of quality variability can convey a positive impact in downstream processes such as refineries. The monitoring and prediction of crude oil inventory levels through the simulation module aids in the proper management of the crude oil uploading process and in the operation of the storage facility within safety margins.

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