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Research Article

Rethinking Petroleum Products Certification

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Facing various challenges in the everchanging refining landscape, it is essential that refiners raise their operations to new levels of performance. Advances in in-line blending (ILB) technology accuracy and reliability have encouraged refiners to take a step forward. Having ILB as a precursor, a new methodology is in concern: the so-called in-line certification (ILC) procedure. Blending processes make use of in-line measurements which, at least in principle, can be used to certificate the product, if the precision and accuracy of available in-line measurements are comparable to measurements provided by standard off-line tests. Such procedure may allow for significant reduction in refinery's tank farming and product inventory, increase of process flexibility, and reliability with benefits to company image. The main limitations for real-world ILC applications in the oil industry remain at the legal and technological levels. This paper proposes novel concepts and foundations of a basic in-line certification model for petroleum products regarding current interdisciplinary challenges and promising solutions.

1. Introduction

Petroleum refining is one of the most important industries, comprising many different and complicated processes with various possible configurations. Globally, it processes more materials than any other industry [1]. Due to the scale and significance of this industry, it becomes more crucial to address the considerable challenges that the industry faces today and in the future.

Production planning and scheduling optimization are essential tasks to maximize refinery's profit margins and to remain in the competitive market. In this sense, several opportunities strictly related to refinery production optimization could be identified. At the strategic level, the supply chain optimization may be posed as a master problem, since there are numerous trade-offs between decisions made at the various nodes of its superstructure in which the refinery planning is embedded. At the tactical level, two major challenges should be addressed by refiners [2].

The first one is that refining industry needs to effectively evaluate process performances to identify options for producing desirable products and meeting increasing constrained environment regulations. The second challenge refers to major transformation from an industry of mainly producing fuels for transportation to one that makes a wide set of value-added products, including chemicals, speciality products, electricity, and hydrogen.

In a scenario in which the world economic growth slowed down and demand for petroleum products flattened or even decreased, it becomes clear that *flexibility* is the keyword for everybody involved in the oil sector [3]. In this sense, online remote characterization and real-time optimization of petroleum products emerge as instrumental technologies for competitive refineries [4]. Such technologies may have a special impact on refining profitability with environmental benefits when considered to provide chemical information of great importance for real-time adjustment of short-term scheduling decisions concerned with product formulation and refinery dispatch logistics.

Blending consolidates as the refinery's last chance to impact profitability at low investment levels and approximately 50% of about 700 refineries worldwide have implemented such technology [5]. Besides positively impacting the overall refinery production scheduling, in-line blending (ILB) operations at the end of the refinery allow for substantial benefits including end product giveaway minimization, lower inventory levels, optimized logistics and, therefore, reduced utility consummations and atmospheric emissions, economic savings in new hardware investment and maintenance, and operational safety.

Apart from typical economical benefits ranging from US$ 0.15 to 0.30 per crude oil processed [6], ILB represents the precursor technology for allowing an additional efficiency jump in refinery scheduling optimization: the so-called in-line certification (ILC) (Figure 1).

As the fundamental premise, an ILC-based approach should consider product dispatch to a third party before sending the official (i.e., legal) product quality certificate to it. ILC procedures are primarily intended to minimize refinery scheduling bottlenecks. However, it is not completely clear yet how large the benefits provided by ILC procedures can be. Since products can be delivered directly from processing to clients, some potential advantages that can probably be related to the implementation of ILC schemes are as follows.

(i) Suppression of conventional operations, as tank homogenization, sampling, and laboratory testing, and this way saves manpower and shortening the refining production cycle time (Figure 2).

(ii) Dead inventory minimization.

(iii) Tankage minimization and associated maintenance costs optimization.

(iv) Improvement of the process reliability and optimization (as process control techniques must necessarily be implemented in-line and in real time).

(v) Enhanced flexibility to tightly specify different product grades according to real-time customer needs.

(vi) Shipping demurrage minimization.

(vii) Enhanced energetic and environmental performances of the refinery storage area provided by an optimized scheduling.

(viii) Staff safety and productivity increase provided by automation replacing manual operations.

Such benefits must compensate the investment on technology and process upgrade required by ILC procedures, if actual implementation at plant site is sought. Apart from legal issues, the refinery's logistic environment will determine how expressive the opportunity for implementing an ILC-based operational philosophy is.

This paper is structured as follows. Section 2 proposes basic concepts and discusses an ILC-based business model.

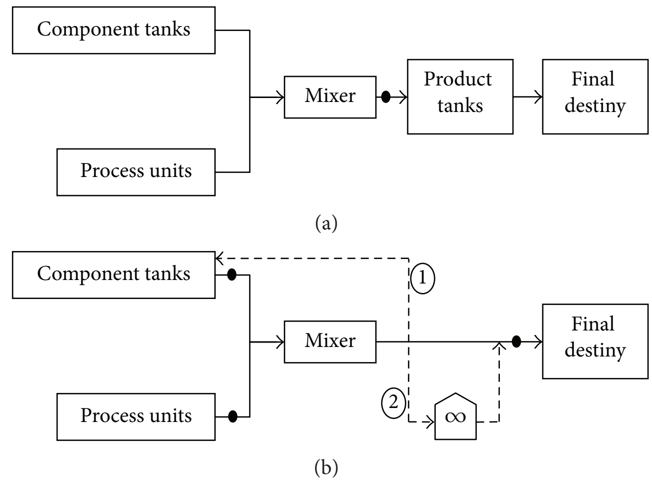

Figure 1: (a) Typical configuration of ILB units; (b) a virtual basic scheme for an ILC unit using two possible routes for off-spec fuels: (1) reblending or (2) infinite dilution. In both schemes, dashed circles represent on-line analyzers.

Some practical ILC implementation issues, with identification of current technical limitations, promising solutions, and required investments, are also discussed here. Section 3 discusses how the ILC scheme should work out in practice in order to be accepted by regulatory agencies and customers in general whereas Section 4 outlines some identified prerequisites to a generic ILC implementation. Section 5 presents the conclusions of the paper.

2. An ILC-Based Custody Transfer Model

Custody transfer in the oil industry refers to the transactions involving transporting physical substance from one operator to another. Since presupposing product *releasing before testing* to a customer, an ILC-based approach implies new technical-commercial paradigms.

2.1. Model Definition. The first step required to support a new proposal or procedure is the definition of important related terms and the development of the basic ideas behind it. *In-line certification* is defined here as a computer-controlled procedure based on real-time data from on-line analyzers able to automatically measure stream qualities and perform actions over manipulated process variables to ensure product specification and optimization this way enabling its prompt delivery from the refinery to third parts prior to the official issuing of the conventional, laboratory-based, *certificate of analysis* (CoA). Here, the term *quality* encompasses any physicochemical property related to the legal specification of a given finished product. Similarly, the *on-line analyzers* terminology encompasses American Society for Testing and Materials (ASTM) on-line analyzers and near-infrared (NIR) systems.

If the in-line certification is thought to simultaneously be performed by an in-line blending unit, one can refer to it as an *in-line blending certification* (ILBC) unit (Figure 3). However,

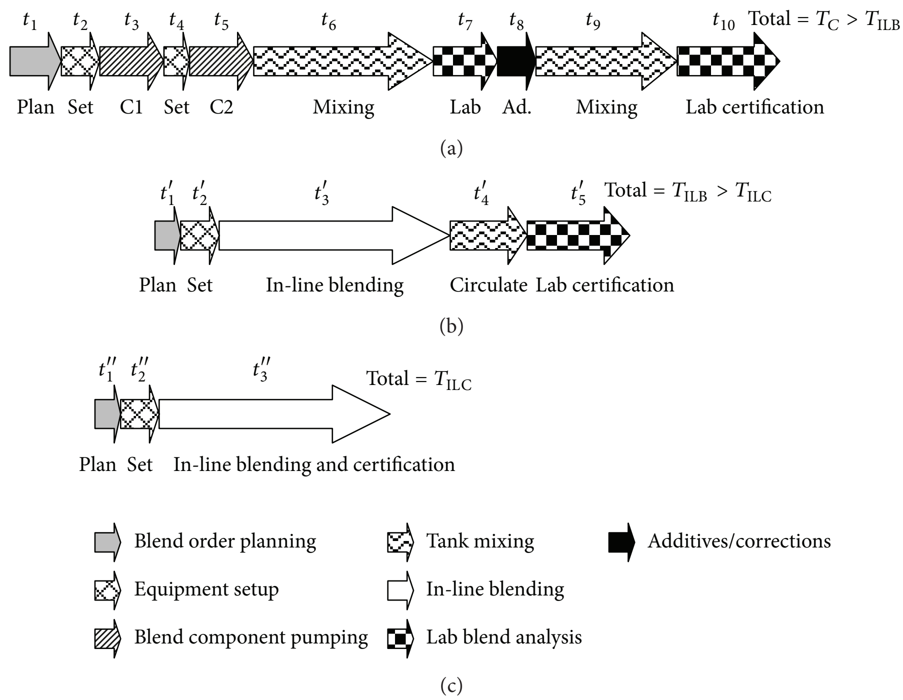

Figure 2: Time saving with ILC [7]. (a) Conventional time (T_C) operation based on manual tank blending and certification; (b) in-line blending time (T_{ILB}) and conventional tank certification; (c) in-line certification time (T_{ILC}) of the finished blend product.

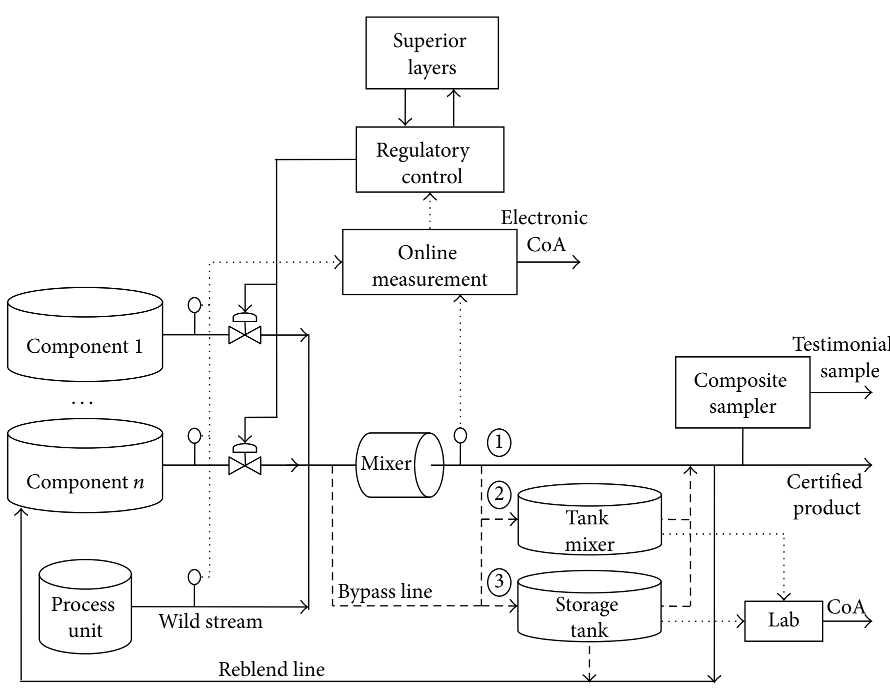

Figure 3: An ILBC unit model using three routes: (1) normal operation condition; (2) blend through precertified tank during periods of abnormal operation condition; and (3) blend to product tank during maintenance periods.

for the sake of simplicity, ILC and ILBC units are generically referred to as ILBC thereafter in this paper. Such integrated engineering approach should be understood as a real-time optimization technology.

Minimal requirements for an industrial ILBC application may also include on-line analyzer validity checking, automatic composite sampler for spot and final checks, and automatic generation of product info reports and their archiving [5].

Once homogenized in a static mixer, the finished blend product is analyzed and then sampled by an auto composite sampler, which retains a *representative sample* (RS) of the overall product delivered to a third part. According to a typical hierarchical planning superstructure, the material quantity that cross the refinery frontier should be defined *a priori* at scheduling level (Figure 4). It defines the *fiscal batch*, whose quality must satisfy the required specification. Right after the fiscal batch production is concluded, an electronic certificate of analysis (ECoA, based on measurements from on-line analyzers) is available and may be sent to the third part, prior to the release of the conventional laboratory-based CoA.

As the basic ILBC procedure premise accounts for automatic product custody transfer right after production, further extrapolations can be suggested, as *segmented fiscal batch*. More specifically, once the transferred volume of product is known and already certificated, there is no reason to wait for completion of the product transferring for product certification. This idea follows a divide-and-conquer strategy, where the whole amount of commercialized product is divided into small fractions that can be certified independently of the remaining ones.

Ideally, the full set of specification qualities should be evaluated in-line at real time by on-line analyzers. However, this may not always be technically feasible since some product specifications are based on experimental assays that are inherently time demanding ones (e.g., gum content for gasoline) or require specific experimental apparatus (e.g., jet fuel smoke point) or even are not quantitative measurements (e.g., cooper corrosion for liquefied petroleum gas (LPG)). In the general case, an ILBC approach should consider a subset of critical (constrained) commercial specifications [8] and indirect measures for well-known behavior or not critical remaining quality variables. In this sense, research on physicochemical inferences development and process statistic control techniques are prolific fields for investigation and applied developments, including novel in-line testing methodologies. In addition to immediate benefits, such new methodologies could serve as truly precursors for promoting interdisciplinary discussions oriented to upgrade legal requirements concerning oil product quality evaluation. In this sense, the US Environmental Protection Agency (EPA) has indeed taken actions to allow refineries and laboratories to use more current and improved fuel testing procedures for ASTM analytical test methods [9]. On the other hand, emerging techniques, as molecular characterization of oil products [10], will stress the need for revising obsolete testing methodologies replacing them by more reliable and accurate ones, potentially interesting for real-time applications [11].

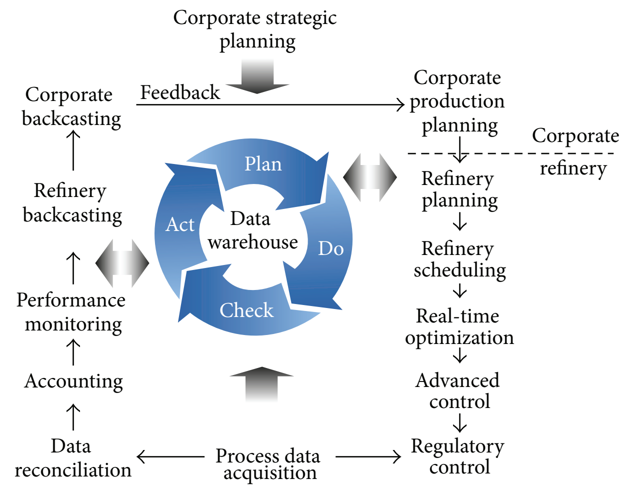

Figure 4: A typical hierarchical decision-making framework based on Moro [3].

After the fiscal batch custody transfer is concluded, a CoA is then produced and sent to the third part. A CoA must present the complete physicochemical characterization of the delivered product, as required by regulatory agencies and usually performed by standard tests, such as those recommended by the American Society for Testing and Materials (ASTM).

In principle, the CoA may be based on either auto composite sampling (Figure 3—configuration 1) or manual tank (Figure 3—configurations 2 and 3) and laboratory testing. Conversely, on-line analyzer measurements have also been considered to compose part of the CoA data. In this case, on-line analyzers should use approved certification test methods, as those defined by EPA 40CFR80.46 (mostly ASTM tests), or correlated to them [5]. If real-time data is considered to final certification, a hybrid or *combined* CoA results (Figure 3). This may be attractive in the sense of optimizing laboratory resources by limiting laboratory testing only for qualities that can not be in-line evaluated. Anyway, each emitted CoA must count on testimonial sample for eventual counterproofing. Testimonials must be representative and consider proper storage against possible degradation reactions.

For pure substances, as the case of petrochemicals, the arrangement of Figure 3 may be simplified if a single component exists and no mixing are required. In this case, the computer-controlled system does not actuate over blending optimization variables but essentially (and directly) over process manipulated variables. This may be the case of propylene plants, a typical first generation petrochemical. Nevertheless, it should be pointed out that even such single systems may consider blending opportunities with off-spec product.

While producing a fiscal batch, the ILBC unit on-line analyzer measurements are integrated by the computer-controlled system. Anytime, if mean product quality does not comply with the specification requirements and there is no expectation of correcting it before batch production conclusion, then the product release should be interrupted. Hence, ILC procedures must also consider fall-back strategies to circumvent such undesired situations. A reblend or reprocess line after on-line analyzer may be provided for ready (automatic) production deviation.

In-line certification should not be confounded with *in-line delivery*, which is exclusively based on the conventional certification of the products after delivery, usually performed to save time and storage at the plant. In-line certification, on the other hand, seeks for a definitive certification solution, as finished products are transferred directly to a third part as a fiscal batch and available in-line instrumentation and techniques are supposed to provide enough information about the product quality in reasonable time (real time) and with high confidence.

Currently, when not legally prohibited, both procedures are typically conditioned by regulatory agencies and are periodically subject to ad-hoc independent audit programs concerned with the computer-controlled system operation [5]. The goal of the audit program is to insure that fiscal batches data and information reported to the governmental entity are accurate and valid. Despite the lack of explicit conditions, regulatory agencies usually reserve their right to make inspections to assure compliance with the requirements (EPA 40CFR80.4).

In legal terms, the US legislation is virtually the most comprehensive one. Technical and legal procedure steps are described by US EPA in USA Code of Federal Regulation, 40CFR80, part 65, which allows refiners legally to blend directly to a third party before finishing product testing and CoA delivery. In Europe, shipping before testing practices have also been mentioned [8] but seem to be mediated by bilateral agreement between refiners and third parties. However, in both US and European cases, the number of refineries operating ILBC-like custody transfer is very limited and the third party is usually, if not always, a transporter company (pipeline or vessel), not a final client (distributor company). Conversely, from the aforementioned cases, in Brazil, the Petroleum National Agency, a governmental entity that regulates the Brazilian oil sector, currently does not allow for finished product shipping before the CoA emission.

2.2. The ILBC Hardware. An ILBC implementation presupposes process hardware properly designed with excellent instrumentation. Blend headers, static mixers, lines, pumps, and valves design should consider operational feasibility and safety accessories during transitory, steady-state, and fall-back conditions. Coriolis flowmeters have been extensively recommended for in-line blending systems [5, 8] and may help to persuade regulatory agencies to approve novel philosophies for custody transfer procedures, as ILBC. In order to reduce stream quality variability from (running) tank components, a tank mixer should be provided with the objective of allowing for inventory homogenization (during) before the fiscal batch production (route 2 in Figure 3). Whenever applicable, filters and coalescer devices for solid and free water removal should also be considered as basic blending system accessory.

At the design level, analytical redundancy should be a project premise. Since real data conciliation may be a valuable tool to the system reliability and early warning of problems, on-line analyzers at each component should be provided in order to produce redundant analytical information whenever possible. Temperature-controlled sampling systems should consider sampling points not susceptible to contaminants and located at critical process points, as components lines, blended fuel line as well as at the refinery boundary if the in-line certified product is then stocked in a tank or passes through it before shipping. Certified reference materials and prototype fuels (or *protofuels*), whose properties are known, require dedicated installations. Fast loops are required to allow for sample movement from process lines to the analyzer house (shelter) and vice versa (Figure 5).

2.3. The ILBC Software. As a real-time optimization business layer, the ILBC operation must agree with the refinery's objectives that are defined at the strategic and tactical levels. This is achievable through capturing the business knowledge in advanced decision-making tools, which should allow for increasing visibility into plant operations and communicating economic drivers to operations allowing them to identify and eliminate constraints by better understanding the planning economic objectives [12].

A schematic representation for ILBC software applications is proposed in Figure 6. In this figure, blending scheduling refers to an off-line optimization layer in which the refinery tactical planning is detailed into short-term operational decisions. Here, fiscal batches are defined and sequenced to execution throughout a time horizon aiming at satisfying the foreseen product requests by customers subject to refinery's operational, logistic, and economic constraints. The *Blend Property Control* (BPC) comprises at least two real-time applications: (a) the multivariable predictive control (MPC), which is responsible by the real-time blended product quality control, and (b) the on-line optimization process model, which should maximize or minimize some performance criteria subject to real-time constraints regarding the whole fiscal batch production. On the other hand, the *Regulatory Blend Control* (RBC) is responsible for manipulating component flows to match an optimal blend recipe defined at the BPC layer. For each predefined fiscal batch volume, the BPC application functions should include field equipment selection and lineup, pump sequencing control, appropriate ramps for blending start-up and conclusion, and additive injections. In addition, the RBC should also be responsible for implementing a trim fall-back strategy in case of system failure. *The Key Performance Indicator* (KPI) is a monitoring module from which the fiscal batch data is collected to compose the ECoA right after the batch conclusion.

It seems clear that the implementation of advanced control schemes must certainly be considered during development of ILBC procedures, as process disturbances are inherent to process operation and lead to some degree of unavoidable process variability. Therefore, process variability must be rigorously considered during the implementation of

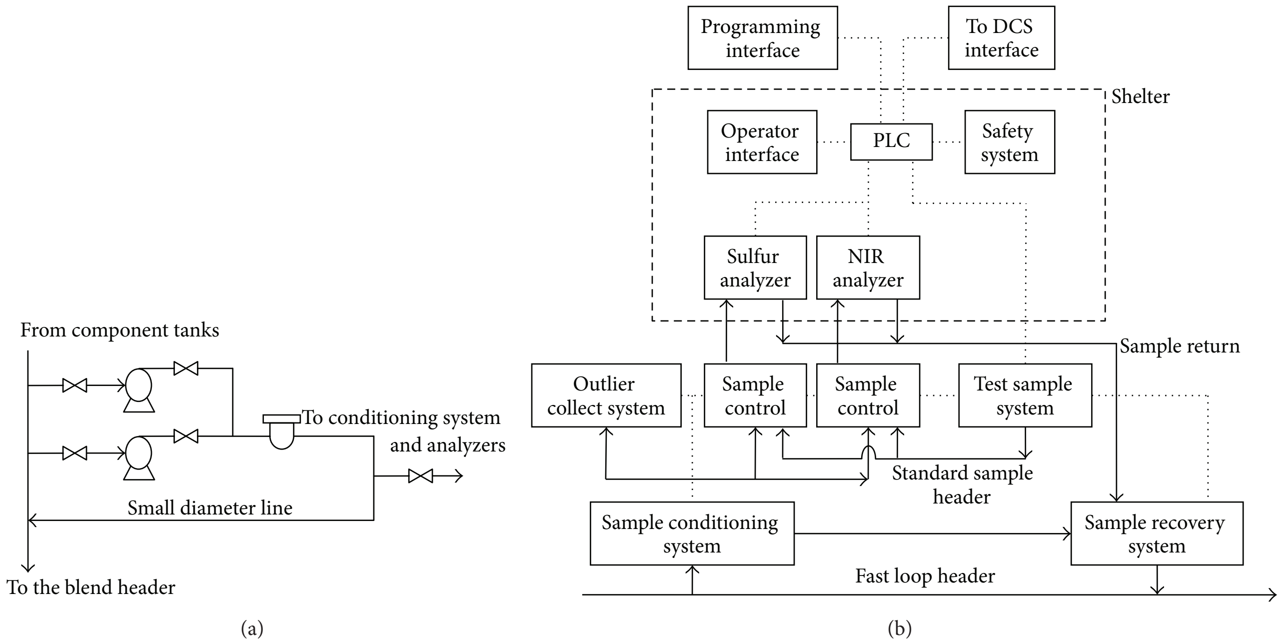

Figure 5: A typical fast loop scheme for refinery ILB. (a) Pumping and filtering; (b) the sample conditioning system.

the ILBC scheme, with the help of sound statistical analyses of measured data performed in-line and on real time.

Similarly, as instrument and operation faults cannot be completely avoided at plant site, the implementation of advanced tools for fault management (perhaps including the in-line control reconfiguration) must also be required during real ILBC implementations, as the process operation must be continued in spite of the faulty event, such as leaking, valve sticking, instrumentation failure, and feed contamination. As a consequence, protection actions and protection mechanisms must be employed to support the ILC decisions and the mechanisms used to maintain the product certification scheme.

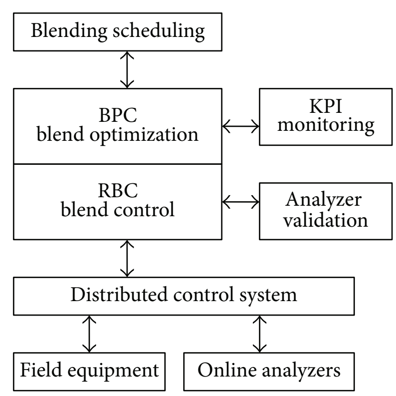

Figure 6: The ILBC software applications.

3. The ILBC Unit Operation

The ILC procedure implicitly breaks the paradigm of the batch operation and, by doing so, suggests a new *modus operandi* for the process operation. It is expected that stream properties in process lines present larger variability, when compared to bulk properties of stored products. Therefore, for the sake of certification, this new vigorous dynamic operation status certainly requires tighter control. However, the proper in-line measurement of the whole suit of fuel properties, necessary to certification, is one of the two major technical challenges. The other one is the analytical accuracy and reliability.

Efforts have been made to address the control problem, but the in-line instrumentation performance has seldom been compared to the off-line standard test ones for the sake of product certification (using repeatability and reprodutibility); correlation measures are provided instead [4, 13, 14]. In this sense, data validation is the key to assure the measurement precision, enhancing the signals of the sensors.

Since instruments must operate in-line for long periods of time, the long-term behavior of process instrumentation must be properly evaluated and characterized. In addition, part of the required properties may be not available in-line due to technological or economic issues. The remaining of this section is dedicated to examine expected problems related to the ILBC low-level operational layers of the superstructure schematized in Figure 4.

3.1. Measurement. Before reviewing the main techniques and instrumentation used to monitor fuel properties, two major practical issues must be discussed: sample representativeness and sensibility to measured properties.

Sample representativeness is especially critical when analyzers require long times to perform the analyses. More specifically, most property analyzers do not operate on a real-time basis since the analyses are complex and time demanding. The product flow rate and the sample size must be defined in such a mode that the on-line analysis shows volumetric compliance without incuring into any constraint on the system production.

Addressing in-line measurement, ASTM D4177 standard focuses on practices for automatic sampling of petroleum and petroleum products whereas the ASTM D6624 standard is concerned with practices for determination of average property values of product streams (FPAPV). Lastly, the ASTM D7453 standard accounts for practices for sampling petroleum products by process stream analyzers.

Another important question refers to the analyzer sensitivity to a particular property. Such a question has been extensively studied in the literature, for example, using NIR technology [13], and different commercial solutions addressing this issue have been released in the market, for example, the FUELex analyzer of the Bruker Optics company. In fact, the search for surrogated variables and correlation development are encouraged. Agoston et al. [15, 16] introduced alternative sensors which enable in-line oil viscosity and corrosiveness monitoring, respectively. Such sensors surely agree with the ILC-based operational philosophy. The ASTM D6708 standard defines some statistical procedures used for assessment and improvement of the expected agreement between two test methods that are assumed to measure the same property of a material.

Concerning the technology used for in-line measurement, in-line specialized analyzers constitute the first reasonable option, at least for simple properties, such as density and conductivity. These analyzers are usually cheap, reliable, and fast, making them appropriate for composing an ILBC scheme. For properties hard to measure in line, inferences based on combinations of electromagnetic spectroscopy and inference models have become very popular both in academic and industrial applications [13]. The combination of NIR spectrometers and multivariate calibration techniques certainly constitutes the most popular alternative for inference development due to fast response times and high precision. In general, NIR systems present better precision (repeatability) than ASTM analyzers and same accuracy (reproducibility) as the calibration method [17] and can produce one complete set of quality determinations in 30 seconds [5, 8]. Real-world NIR in-line applications have become very attractive, since 10 or more product qualities can efficiently be evaluated with NIR technology (diesel or gasoline) herein its ability to predict blend indices which are extensively used in off-line applications, as refinery production planning and scheduling. Practices for infrared multivariate and quantitative analyses are addressed by ASTM E1655. On the other hand, while equipments based on nuclear magnetic resonance (NMR) have also been investigated with comparable performance [18], less applications have been verified.

As pointed out by some authors [19], NIR-based analyzers require careful building of the inferential property model. However, suppliers of NIR-based analyzers offer poor modeling support and do not provide guarantees for measurement performance [20]. Acceptable performance assumes that the defined ASTM precision is reached at least 90% of the time during normal operation with no more than two model updates every year [20]. Other common complaints include filters clogging and product film deposition on optical parts. Proper instrument installation standards are described in ASTM D6122, which recommends sample conditioning systems design including automatic probe wash and regular model validation (daily or twice a day) [20].

Alternative manners to cope with the aforementioned problems are based on identification and analyses of the actual sources of property variability: the sample composition [21]. It is well known that the composition of a mixture can drive its chemical and physical behavior [14]. Recently, a promising branch of analytical chemistry based on advanced mass spectrometry, usually named FT-ICR-MS or simply FTMS [21], has been applied to determine the fuel properties based on a detailed composition of the sample. This has led to development of a new family of analytical techniques called *petroleomics*.

Although these techniques are still incipient and practically restricted to laboratories, typical analyses last from 5 to 15 minutes, making feasible in-line implementations. More mature techniques that can be used to provide the detailed composition of oil products include bidimensional (2d) chromatography, especially GC×GC and GC×MS [22]. However, the main disadvantage in this case is the trade-off between data resolution and the time required for analyses, around 80 minutes. Specifically, chromatographers can utilize very different columns, with different lengths and diameters, which influence resolution, analysis time, maintenance (clogging), and so forth.

Since the abovementioned equipments measure compositional variables, it is necessary to implement particular knowledge to convert such data into specified properties. In this subject, quantitative structure-property relationships have shown very promising results [23, 24], despite the sparse data of pure compounds. Table 1 shows a summary of the measurement technologies discussed here.

A plausible model for producing a combined CoA may be based on Figure 7 schematics, where the NIR predictions are first generated during in-line blending and the QSPR predictions are then generated, using the compositional analyses carried out by chromatographers or spectrometers.

3.2. Validation. At the second level of the operation hierarchy, validation of obtained measurements must be performed in order to assure product certification. Such control layer enhances the measurement quality by identifying outliers, noise, or data trends and, if necessary, performing data reconciliation. Moreover, in case of identification of off-spec materials, protection mechanisms must detect and execute the necessary actions to ensure process safety and product quality.

Data validation is usually carried out by characterizing the measurement error, frequently measuring protofuels. Alternatively, results obtained by on-line analyzers can be compared to standard laboratory results according to statistical techniques aiming at detecting and quantifying

Table 1: Technologies to integrate an ILBC-based operation model.

Technologies	References	Pros	Cons
Spectroscopy	Gilbert et al., 2004 [18] Morris et al., 2009 [13]	Fast analysis; high precision; low prices	Subject to local and periodic calibrations; insensitive sulfur compounds
(2d) chromatography	Yang et al., 2002 [25] Wang et al., 2005 [22]	Compositional data; established technology; varied configurations	Trade-off between analysis time and data resolution for real-time applications
Mass spectrometry	Marshall and Rodgers, 2004 [21]	Fast analysis; ultrahigh resolution; detailed characterization;	Qualitative data, due to ionization deficiencies; high prices
Quantitative structure-property relationships	Creton et al., 2010 [23] Saldana et al., 2011 [24]	Fundamental knowledge; universal applications	Few pure compound properties known; small data bases

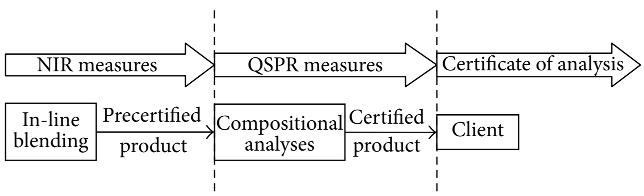

Figure 7: Basic ILBC analytical steps.

discrepancies. The main standard practices available for validating on-line analyzers are ASTM D3764, for performance validation of process stream analyzers, ASTM D6299, for statistical quality assurance and control charting techniques of measurement systems, and ASTM D6122, for validation of multivariate on-line, at-line, and laboratory NIR-based analyzers.

Due to well-known limitations of conventional validation practices, which are usually performed with long time intervals, the measurement reliability is not ensured during the whole period of product transferring. Besides, precision and accuracy of nonconventional on-line analyzers are insufficient for product certification or have not been characterized. In this scenario, simple multivariate techniques, such as principal component analysis (PCA) and canonical variate analysis (CVA), can be of great interest to provide process data at short time intervals and reduce uncertainties, improving data repeatability and reproducibility [26].

Basically, multivariate techniques use correlations of properties measured by different on-line analyzers to increase data redundancy and to enhance capabilities for process fault detection. Abnormal behaviors can also be detected by comparing current data with successful historical runs. For example, NIR and FTMS analyzers can provide electromagnetic and mass spectra that can be used directly to provide operation states and monitor the process behavior [27]. In case of sensor malfunction or maintenance, multivariate techniques can be used to estimate the missing properties based on correlations with measurements provided by other sensors and/or historical models, allowing for acceptable ILC robustness [26]. In case of process fault, automatic protection actions must be triggered, such as segregation of the off-spec components or product, in order to guarantee the ILBC premises.

Figure 8 illustrates the worst validation scenario of the proposed ILBC scheme, in which all components behave abnormally, yielding an off-spec product that must be isolated from the jetty line. After problem detection with the help of electromagnetic spectra and petroleomic tools, the product is then sent back to an off-spec product storage tank through a recycle line, for posterior reblending or reprocessing.

3.3. The Human Organization. Changing attitudes, revising previous assumptions, and rethinking best practices for refinery operation are particular challenges of all in performing optimization.

Actually, rather than an interdisciplinary activity in nature, ILBC operation must be understood as a very specialized optimization activity inside refinery. A major challenge to successfully implement an ILBC technology may indeed be educating the refinery's personnel to work according to new paradigms and work process.

Since at the refinery technical-commercial boundary, the ILBC operation is not only strongly dependent on the refinery production scheduling but also provides a vital feedback for its daily updating. Such collaborative scheduling formulation may be especially important for refineries embedded in a very competitive environment, in which scheduling is usually market oriented. In this sense, rather than any computational systems, the quality of the staff may be posed as the prime success factor, along with their ability to work as a single team, despite focusing on distinct problems and tasks [12].

Best work processes in turn enable the personnel to consistently achieve production plan objectives. Therefore, work process should be independent of personnel changes. This is accomplished via structuring a refinery team responsible for the ILBC unit performance. Some critical characteristics of a successful team are identified. As pointed out by Barsamian

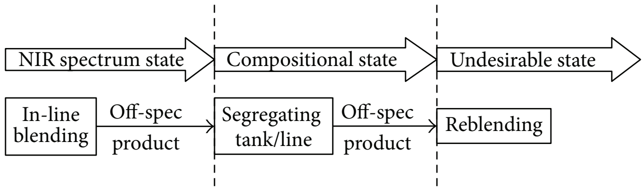

Figure 8: Segregating route of ILC procedure.

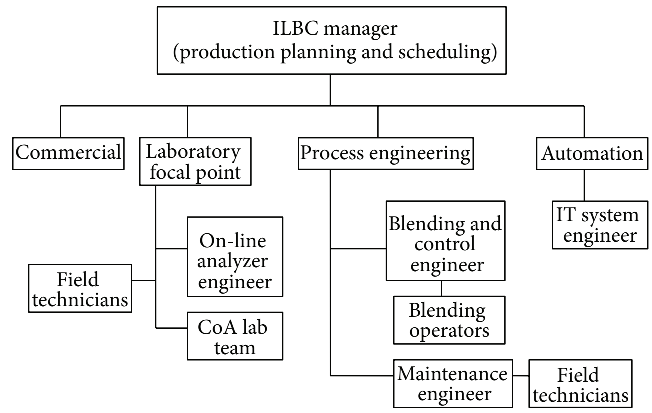

Figure 9: A ILBC team model [5].

[5], thinking and working oriented to "do things right the first time" should drive local raining people's attitudes and mindsets aiming at supporting the ILBC unit. Rapid communications, faster response times (analyzer repairs with high priority), key people on call, and management motivation of ILBC team members are mandatory practices that motivate a matrix type organization in which the individuals remain physically in their respective areas, but their daily work responsibility is to the team (Figure 9).

The ILBC team is responsible for the daily operation of the ILBC unit. It comprises tight monitoring of performance indicators including critical analysis of the nature and frequency of operational issues and incidents, definition of priorities related to system maintenance and upgrading, resource forecasting to ensure high factors of system availability and reliability, and managerial follow-up.

The most prominent change in the refinery's personnel profile is certainly experimented by the laboratory staff. Not only a new work philosophy must be learned, but also a set of more added-value activities should be performed. Since now focusing on the on-line analyzers performance, the laboratory's staff must be qualified to locally provide process streams and fuel additives spectral modeling, protofuel management, research on physicochemical inferences development, and equipment monitoring and maintenance. As product certification process is expected to be less demanding for laboratory ASTM analysis of manual operational routines, as periodic line and tank sampling, mechanical work should be replaced by challenging activities performed by high-profile professionals. On the other hand, it is uncertain to say that ILBC automation will cause the reduction of laboratory activities. Anyway, it is worthwhile to note that those refiners that did not reduce their technical staff when automation was introduced have experienced gains in operational safety [28].

Since such technologies are a major concern as they impact the entire plant schedule and real-time optimization process applications, a highly qualified and integrated blending team becomes instrumental to the modern refining industry.

3.4. Superior Control Layers. The remaining control layers of the proposed ILBC operation hierarchy are concerned with the blending process operations. However, it is important to note that (a) product delivery underscored by ILBC technology is faster than the conventional one (Figure 2) and (b) on-line properties measurements present more vigorous dynamics and this way requires tighter control. Once the property mixture rules and indexes are known and the inferential models are implemented, NIR-based analyzers can quickly measure the feed and product properties [19]. Hence, it allows for a more sensitive control using both feedback and feed forward control structures. An important feature of on-line measurements of oil properties is the higher frequency of analyses, which enables improved process operation and more frequent optimization of process setpoints. For instance, both electromagnetic and mass spectra can offer essential information for definition of the best recipe for a particular production run [27].

4. ILBC Prerequisites

Custody transfer involves industry and legal metrology standards, contractual agreements between the parties, and governmental regulation and taxation. Therefore, any concrete investment decision on ILBC implementation should be preceded by an interdisciplinary analysis of the refinery and the environment in which it is inserted. Major issues are addressed in this section, as follows.

4.1. Technical Issues. At the technical viewpoint, an ILBC unit may be understood as a forward step of a reliable ILB unit. The success of an ILBC implementation is conditioned to the maturity stage of the refinery ILB automation technology as well as its previous experience in dealing with ILB operations. Table 2 summarizes major qualitative characteristics expected to further raise a successful ILBC application.

4.2. Legal Issues. The first question that must be considered prior to legal implementation of an ILBC procedure is the following: is it legally permitted?

Under the preceding US EPA proposition for shipping before testing based only on on-line analyzer control of properties of interest to EPA (USA Code of Federal Regulation, 40CFR80, part 65), governmental regulatory legislation worldwide should be expected to be revised in the light of the fast development of ILBC technology as well as due to environmental pressures, since it may optimize volatile organic compound emissions at the end of refinery. As a result, the formulation of new *modus operandi* and mechanisms to

Table 2: Some critical technical requirements for an ILBC-based operation model.

Discipline	Item	Prerequisite
Analytical	ASTM analyzers	Reliability
	On-line analyzers	Robustness Sample condition system Redundancy with on-line ASTM analyzers
	Sampling	Sampling conditioning systems (on-line measurements) Automated composite sampling
	Laboratory	Laboratory NIR spectrometer Reference materials/protofuels Spectral database (protofuels, streams, and additives)
Information technology	Real-time database	Process streams data storage (extensive/intensive properties) Discrete and continuous plant data storage (e.g., on/off flows, tank heels)
	Off-line database	Process configuration (e.g., equipment operational limits)
Process engineering	System design	Allowing for redundant measurements
	Process modeling and control	Reliable inferences to noncritical product qualities MPC regarding feed forward on components blend indices Blending RTO technology Ratio control including fall-back strategies
	Oil movement system	Integration to refinery production scheduling Automated plant operation management (i) Tanks: swings, heel qualities, and stratification detection (ii) Line ups: flushing, valve position, and pipe quality tracking
	Data validation	Real-time data reconciliation on flows On-line analyzer data validation on ASTM analyzers

ensure consistent ILBC implementation and customer rights may be propelled by prospective studies and pilot projects by the oil industry.

4.3. Commercial Issues. The ILBC approach may be particularly attractive for vicinal companies operating local continuous-flow product custody transfer among them. This may be the case of integrated industrial pools involving refinery and petrochemical plants.

Once the ILBC operation mode is identified to potentially bring substantial benefits to both the buyer and the seller, a number of issues should be addressed. Since representing the ultimate manufacturing step, severe consequences may arise in case of system failure including economics and reputation damages. In this sense, a comprehensive analysis of hazardous events should be done and translated to contractual agreements if not properly addressed by the governmental legislation.

Rather than spot commercial contacts related to demand forecasting and CoA emission, such real-time integrated operation implies a high level of multidisciplinary human interactions between the personnel of both parts, including collaborative technological efforts to ensure reliability of the continuous operation and monitoring, including common fall-back strategies.

5. Conclusions

Facing various challenges in the everchanging refining landscape, it is essential that refiners raise their operations to new levels of performance. To help refineries improve its competitive edge and smoothly change to future refining operation, this work has introduced a new paradigm concerned with the high performance refining: in-line certification.

This subject promises to revolutionize the whole picture of refineries production by upgrading the blending process operations to new ends and legal threshold. The use of old-fashioned and unreliable analyzers, which perform long-run analyses, may be in close connection with the historical background of the petroleum business but should not necessarily remain the same in the near future, given the fast technological development of new instruments and novel analytical techniques. Compound identification can be programmed more easily and cause the reduction of uncertainties and subjectivity, suggesting that future ILBC procedures may have close connection with petroleomics.

This revolution can bring a series of advantages that can allow for implementation of an ILBC approach in the near future. Technical-economic advantages as well as interdisciplinary challenges to be addressed were outlined and discussed. In-line measurement was identified to be the key issue for a successful certification model. The inherent measurement complexity of some specified properties demands very dedicated analyzers, which generate uncertain and/or subjective data after long analysis time. Potential surrogates for these analyzers were discussed, including the well-known NIR-based and new petroleomics-based techniques. Data validation and reconciliation were pointed out to have an important role in the ILBC approach, ensuring the required reliability for a real-world application. Complementary discussion on promising process control strategies and human organization for supporting ILBC operation were also presented.

At the managerial level, clear refinery business objectives including minimum inventory policies, flexible, nevertheless optimized, scheduling to efficiently capture commercial spot opportunities and low demurrage aiming at minimizing jetties occupancy should be praised as well as the commitment of the refinery staff with a realistic scheduling and its economic performance. Therefore, new work processes based on an interdisciplinary dedicated team whose core skills include (a) fast communication according to an efficient organization workflow in which reliable information (data and models) is available on time, (b) know how autonomy to promptly solve maintenance problems locally at the refinery, and (c) new procedures regarding chemometric model maintenance, reference samples management, analyzers validation, on-line sampling, fall-back strategies implementation, and customer claims.

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