7
General Conclusions and Future Research Directions

This final chapter aims to draw the thesis conclusions, highlighting the main contributions of this work. As presented in the introduction, the purpose of the present thesis was to address the problem of integration and coordination under uncertainty in the oil supply chain at different decision levels (tactical and operational). *Spatial integration* was addressed at the tactical level (considering range of activities of the oil chain), whereas the *temporal integration* was addressed in the interaction between the two levels (tactical and operational).

First, an overview of the refining industry was presented in order to contextualize the reader about the problem presented at this thesis. Next, a literature review based on forty papers (40) about refinery planning models was conducted. The review emphasized the main techniques to deal with optimization under uncertainty. Almost all of the twenty two papers (22) papers that consider stochastic models show the demand as an uncertainty factor, and most of them also consider the product price variation. On the other hand, uncertainties in the supply and the process unities capacities, as considered in this thesis, have been rarely explored in the literature. The integration of different planning levels is also a rarely subject studied in the oil supply chain. Despite of the many contributions in *spatial integration* (horizontal integration), *temporal integral* (vertical integration) has been little investigated in the oil supply chain studies. Since no refinery planning models that consider the integration of operational and tactical planning decisions were found in the literature, this is the main academic contribution of this thesis. Actual applications were also highlighted in the literature review. In spite of the increasing number of papers that consider actual cases, most of them are small instances of the real problem. In the case studied in this thesis, large scale problems were investigated, which also represents an academic contribution, as it indicates the feasibility and hence the relevance of the approach.

Before establishing the integrated approaches for the tactical and operational planning of multisite refining networks, a tactical and an operational mathematical programming models were proposed with the objective of maximizing the total profit over a given time horizon. Both tactical and operational models are two-stage stochastic linear programs. Uncertainty was incorporated in price and demand parameters at the tactical level and in oil supply and process capacity unit parameters at the operational level. The proposed tactical model was adapted from the model proposed by Ribas *et al*. (2010) by excluding the investment decisions. This model aims to maximize the expected profit of the oil chain, considering refinery operations constraints, logistics constraints, and market constraints. The operational model was based on the work of Neiro and Pinto (2005) and maximizes the profit of each refinery subject to resource and time constraints. The main contributions of the operational model are the presentation of a detailed formulation, the modeling of uncertainty in oil supply and in process capacity units, the inclusion of a set of operational modes into the model, and the addition of a decision variable to represent an option for oil purchase at the spot market. This greater detail of modeling, including refinery characteristics, allows more stable and less riskier decisions. An industrial scale study using data from the Brazilian oil industry was conducted to evaluate the benefits the proposed tactical and the operational models and their industrial feasibility. The solution obtained was suitable to real refining planning activity of the oil industry and the resulting product specification values obtained were within specifications. Thus, it can be concluded that modeling uncertainty in the oil chain provides a more practical perspective for this type of problem.

As stated by Candler and Townsley (1978), formulations ignoring the lower level objective (single-level formulation) may lead to very inconsistent results, in the sense that the lower level may not be feasible given the highest level allocations. Thus, single-level formulations can be visualized as centralized decision making systems where the highest level dictates orders to the lower levels. The integrated problem, however, deals with coordination decision making process in a decentralized system, by improving the objective of the highest level, considering the improvement of the lower level objectives. So, integration and coordination are important features in enterprise-wide optimization. In addition, the integrated planning requires centralized information which is a benefit for knowledge preservation and avoids a lack of information between the two planning levels. Two temporal integration approaches were proposed in this thesis for the integrated planning of the oil chain. The hierarchical approach considers one way information flow (from the tactical to the operational model). The iterative approach, on the other hand, considers a feedback from the tactical to the operational model. The benefits from integrated planning of multiple sites may not only appear in economic terms but also in terms of process flexibility. These benefits were discussed in the context of a numerical study and the results from the *hierarchical* and *iterative* methods were compared. The benefits could be measured not only by the decrease of the oil purchase in the spot market, but also by increases in the total expected margin as well as the more efficient utilization of the available capacity of the process units. Plan stability (or robustness) is also a very welcome benefit for management.

All in all, as practical contribution, the integrated stochastic approaches developed in this thesis may offer to the decision-makers a holistic view of the problem. They also allow an accurate evaluation of the problem uncertainties, which can turn out to be a competitive advantage in the uncertain oil refining business.

7.1. Suggestions for Future Works

The fundamental issue in the area of planning is the integration of models across very different timescales (Shah, 1998). The multiscale optimization challenges are: (1) how to coordinate the optimization of these models over a given time horizon (from weeks to years) and (2) how to coordinate the sourcing and investments long-term decisions (years) with the production planning and material flow medium-term decisions (months) and with the scheduling and short-term operational decisions (weeks, days) (Grossman, 2005). Major issues in this sense involve decomposition procedures that can effectively work across large spatial and temporal scales. The total integration of different decision levels is also a challenge in this area. The reformulation techniques for bilevel programming problems by employing the Karush–Kuhn–Tucker (KKT) optimality conditions of the lower level problem transform the original problem in a single level optimization problem but add complexity (nonlinearities) to the model. The study of methods to deal with this additional complexity is recommended. In this regard, problem reduction techniques such as aggregation of constraint/ variables or decomposition procedures may be pointed out as an alternative to solve the resulting large scale problems.

As a future works, this research could also be extended to include discrete decisions (to model, for instance, minimum quantity of oil purchased and choice of operational modes requiring minimum quantity of material to be processed) and nonlinearities (arising from the final product specification). The communication between the two models (tactical and operational) could also be established based on variables other than the purchase of additional oil, for example through additional oil prices at the spot market. The lower margins obtained in Case 3 indicate that the criteria of force spot purchase equal zero at the end of the iterative approach may not be appropriate. Another criterion to stop or to allow greater exchange in the oils from long-term contracts may be more appropriate criterias. More variables could also be included in the first stage at the operational level, for example, demand for refined products.

As the traditional two-stage programming used in this study provides a risk-neutral approach, the problem could be reformulated as robust stochastic models to account to a risk-averse point of view. Developing methodologies for scenario generation could provide great benefits to the consistency with the real problem studied as well. In addition, the problem could be extended to a multi-stage (and multi-period) point of view, considering the different time of the decisions in the tactical and operational planning levels.