Chapter 6
Conclusions

In this thesis we have addressed the investment planning problem for the petroleum supply chain under demand uncertainty. We have formulated and solved a two-stage stochastic programming model that aims at accurately representing the particular features that the problem presents, especially regarding the details that are inherent to the investment planning for the petroleum logistics infrastructure.

We propose a two-stage multi-product, multi-period model that are capable of making decisions of both strategic and tactical nature. This sort of integration is imperative in the context of the investment planing problem because of the inherent dependency between tactical decisions, such as inventory and transportation levels, and strategic decisions, which can be seen as the selection and timing of the logistic hardware that the system would have available to make those tactical decisions. This integrated approach is crucial in order to avoid suboptimal (or even infeasible) decisions due to an eventual lack of information sharing between these two decision levels.

In addition, we accepted the challenge of considering the demand uncertainty into the investment planning process as we believe that it is crucial in the context of the petroleum supply chain planning problem. Nevertheless, the incorporation of the uncertainty was not a trivial task because of the inevitable increase in the complexity of the problem due to bigger scenario sets. Moreover, we observed that the problem approached becomes quickly intractable as the number of scenarios grows, which would prevent us of having good representations of the stochastic phenomenon.

We circumvent the drawback of complexity increase by considering two different strategies. First, we developed a framework that allowed us to control the number of scenarios required to reach a prespecified level of tolerance regarding solution quality by means of a simulation-based strategy. Such a strategy is known as Sample Average Approximation (SAA) (Shapiro and Homem-de Mello, 1998) and it allows us to derive approximation to the true optimal solution considering samples of controlled size. We showed that we can use the size of the sample as an input to be associated with a statistical confidence level. We believe that by doing that we are providing the decision maker with a quantitative and reliable measurement of the trade-off between complexity (i.e., the number of scenarios to be considered) and solution quality (which can be evaluated using the proposed framework).

The second strategy is related with how efficiently we can solve the stochastic programming problem, provided that the sample size is already defined. We noticed that the investment planning problem under demand uncertainty has a particular structure that was possible to be exploited by means of a scenario-wise decomposition. Bearing this in mind, we proposed two novel approaches that focus on decomposing that problem in a way that it could be efficiently solved and recombined. Even though they were designed in the context of the problem considered in this thesis, they are both general and could be readily applied to a wide range of problems that shares the same structural characteristics.

We believe that we achieved with this thesis the objective of bridging the distance between theoretical research and large-scale real-world applications, considering that we have successfully applied modern optimization knowledge to design tools that are capable of efficiently solving the problem approached.

6.1 Thesis Contributions

In this section we list the main contributions that this thesis has to offer to the present state-of-art of the field. These contributions are as follows:

- The development of a mathematical model for the optimal logistics planning of oil product distribution considering issues of tactical planning to evaluate decisions of a strategic nature. For this purpose, we have detailed the specific features of the logistics of petroleum products distribution and the possible investments that could be made in its infrastructure.
- The consideration of the uncertain nature of the problem in a more comprehensive way than is usually found in the literature for planning the supply chain of petroleum and its by-products through the use of SAA. We are not aware of an existing application of such a technique to the optimization of the petroleum products chain.
- The use of SAA as a tool to manage the scenario generation combined in a sampling framework is a novel feature in the field. We believe that this technique has two main positive features: its simplicity in terms of experimental design and implementation and the fact that it can be statistically certified in terms of confidence intervals. We believe

that these characteristics make the proposed framework a simpler, yet powerful alternative to other scenario generation techniques might be as not straightforward to understand, evaluate, and/or to implement.

- The development of an novel exact algorithm for solving the supply chain investment planning problem under demand uncertainty based on stochastic Benders decomposition. We showed how we can implement the algorithm exploiting the block-angular structure that the problem presents which, combined with the fact that the two-stage stochastic problem has complete recourse and continuous second-stage variables, allowed us to implement an efficient a scenario-wise decomposition procedure.
- We developed novel acceleration techniques for the proposed stochastic Benders decomposition that improves the traditional framework in terms of computational times for the problem considered in this thesis. Nevertheless, we would like to highlight that the acceleration techniques proposed are general and can be readily extended to a wide range of problems that share the same structure.
- It might be the case that some particular feature of the problem considered requires some of the variables of the second-stage problem to be integer. To address this issue, we propose a novel decomposition approach that also aims at exploiting the block-angular structure of the problem, however being capable of dealing with the nonconvexity in the second-stage problem caused by the presence of integer variables, and with the fact that the recourse is no longer complete. We rely on Lagrangean decomposition to propose a novel algorithm that efficiently solve the stochastic integer problem in this case.
- We showed that the nonanticipativity conditions commonly used in the context of Lagrangean decomposition can be formulated in alternative ways in the case of stochastic integer programming problems and that it can influence the performance of the algorithm in this case.
- We developed a novel methodology for updating the Lagrange multipliers that is based on a hybrid approach which combines cutting planes, subgradient, and trust-region frameworks. Once again, we would like to emphasize that it is a general technique that can be applied to a wide range of problems.
- We showed how we can insert risk considerations into the mathematical model, and consequently into the decomposition framework, without

compromising the decomposable structures nor increasing the complexity of the problem.

– We focused on a case study that is oriented towards a region of Brazil with very particular characteristics regarding the distribution of petroleum products. The implementation of the proposed approaches led to important conclusions regarding the planning of logistics investments in the region. Again, we are not aware of the existence of previous academic papers that are concerned with this area of study.

6.2 Future Perspectives

There are some topics that we believe their study would further validate the efficiency of the proposed decomposition frameworks and allow us to extent the proposed ideas to a wider range of applications. We list these topics below:

– We assumed that our problem could be approached by means of a two-stage stochastic programming model. By doing so, we are assuming that the selection and timing of the projects must be made in anticipation of the whole time horizon. Even though it is a simplification, it actually makes sense in the context, provided the length of the time horizon and the characteristics of the projects considered in this case. However, it would be of great interest to consider the possibility of reviewing these decisions, by means of a multi-stage programming approach. It is known that in this case the problem would become more difficult to handle, thus requiring particular approaches.

– Consider alternative ways of generating scenarios in this case might be an interesting direction to investigate. Also, the consideration of different sampling strategies would provide more accurate samples, which would possibly improve the quality of the solution approximation.

– Even though we presented the SAA and the decomposition techniques as separated tools, we would like to emphasize that the combination of both is promising as for improving the quality of the solutions obtained, as well as increasing the efficiency of the process of obtaining solutions. Remind that the presented decomposition strategies would allow us to consider larger numbers of scenario, thus improving the precision of the solutions obtained.

– Apply the acceleration techniques for the stochastic Benders decomposition into a broader set of problems, in order to evaluate its efficiency into different contexts. We also believe that the development of more exhaustive sensitivity analysis of the algorithmic performance to variations in user-specified parameters deserve further examination in a future study.

- Test the proposed Lagrangean decomposition techniques into a different set of problems as well as assess the sensitivity of the proposed approach to the user parameters definition. In addition, further investigate the effect of different formulations for the nonanticipativity conditions in the computational performance of different algorithms and/or Lagrange multiplier update strategies.
- Both techniques can benefit from the use of parallelization. In the case of the stochastic Benders decomposition, the Dual Slave Problems could be solved independently, what would render some saves in terms of computational times. We believe that these savings would be even greater in the case of the Lagrangean decomposition, especially because most of the solving time in this case is dedicated to solve the independent mixed-integer problems for each scenario. How one could manage the parallel solution of this subproblems is an issue that should be addressed in order to push even further the limits on the size of scenario sets.
- Even though the expected shortfall can be used as a risk measure and efficiently reduce the risk, it is known that this measure is noncoherent (i.e., this measure does not hold the properties of monotonicity, subadditivity, homogeneity, and translational invariance). We believe that the investigation on how one can incorporate coherent risk measures (such as Conditional Value-at-Risk) into the decomposition framework without ruining the decomposable structure of the problem requires further efforts.