5
The need for Integration in the Oil Supply Chain

Decisions are made at different links of the supply chain (procurement, production, distribution, and sales) and at different levels in the planning hierarchy (strategic, tactical, and operational). They mainly differ in the range of activities in the supply chain (horizontal integration), planning horizon (vertical integration), and process detail (data aggregation versus constraint propagation) as can be seen in Figure 16. Whereas the horizontal integration deals with issues related to *spatial integration* which involves coordinating the activities of the supply chain, vertical integration is related to *temporal integration* which involves coordinating decisions across different time scales (Grossman, 2005). In addition, decision details increases in the shorter planning time frames. Aligning each step of this complex process is critical to competitive advantage because it provides the basis to optimize the decision-making in an enterprise through the information technology infrastructure (Lasschuit and Thijssen, 2004; Grossman, 2005). In this context, research and developments in the integration aspects have gained important practical significance, as observed by Li (2004). Reklaitis (1991), Rippin (1993), Shah (1998), and Grossmann (2005) reviewed planning and scheduling problems and summarized the main future challenges as the development of effective integration and coordination of different planning models on single and multisite systems, the modeling uncertainty through adequate stochastic models, and the development of algorithms tailored to provide proper solution techniques for these problems. In this respect, the formulation and solution of mathematical models is the one of the most important approaches for achieving planning integration because they have been proven to offer effective tools (Li, 2004; Zhang and Zhu, 2000; Bassett *et al.*, 1996a; and Bodington, 1995). The current drive towards enterprise-wide optimization offers an indication of renewed efforts towards this end that are aided especially given the improvements in scientific computing and information technology in recent years (McDonald, 1998, Ryu *et al.*, 2004, Grossmann, 2005).

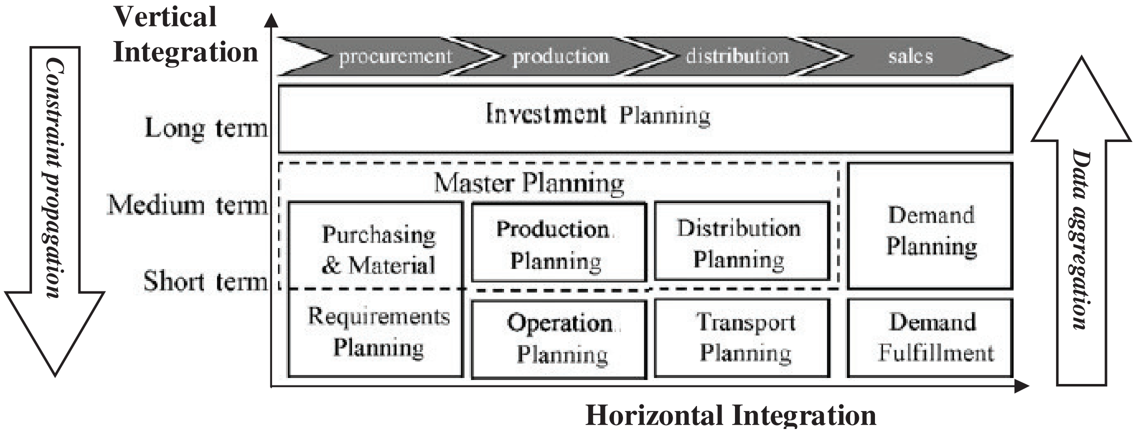

Figure 16. Decisions at the supply chain planning (based on Kreipl and Pinedo, 2004, Lasschuit and Thijssen, 2004, and Maravelias and Sung, 2009)

The oil refining activity is certainly one of the most complex activities in the chemical industry because refineries carry different processes with several possible configurations and structures (Khor and Elkamel, 2008). Consequently, the integrated refinery planning is considered one of the most difficult and challenging applications of large-scale optimization, but the expected outcomes would be commensurable with effort, time, and resources invested (Zhang and Zhu, 2000). The use of mathematical programming in the refining planning activities was shown to lead to potential gains of US$10 per ton of refined product (Moro, 2003) that corresponds to savings of more than 300 million dollars per year in large refineries. However, such a gain is extremely difficult to achieve because of the complexity of oil refining activities. This challenge is prompting refineries to continuously seek, demand, and implement efficient tools and technologies with the ultimate aim of total optimization through integrated planning (Li, 2004; Bodington, 1995). The works by Kim *et al.* (2008), Al-Qahtani and Elkamel (2008), Guyonnet *et al.* (2009), Ribas *et al.* (2010), Al-Qahtani and Elkamel (2010b), Carneiro *et al.* (2010), and Park *et al.* (2010) are examples of recent studies on horizontal integration in the oil supply chain. Despite of these contributions, vertical integration has been rarely explored in the oil supply chain studies. The works by Joly *et al.* (2002), Pinto *et al.* (2000), and Luo and Rong (2009) are examples of efforts in the integration of planning and scheduling problems. No refinery planning models that consider the integration of operational and tactical planning decisions were found in the literature.

As mentioned previously, data are more aggregated at the tactical level than at the operational level. The master tactical model (high-level) is used to assign production targets to refineries and the slave operational problem (low-level) details the operation processes at each refinery breaking the aggregate planning (master planning) down. In this regard, uncertainty is an important motivation to the integrated tactical and operational planning of oil refineries. Because in the solution of the two models separately (single-level formulations), the tactical level does not take the operational uncertainties into account (the tactical level is "blinded" to the operational uncertainties), large errors may be introduced to the problem. In the planning problem addressed in this thesis, the tactical model defines the oil allocation from long-term contracts (fixed oil) to each refinery, but due to delays/changes in the oil supply at the operational level, the amount or quality of the oils received by the refineries may not be enough to meet their product demands. In this case, the refineries need to purchase additional oil at the spot market which means a change in the tactical solution with implications to the oil supply (if the additional oil is not commercially available or cannot be produced by national oil sources) and logistical constraints (if there is no capacity for transportation or storage for the additional oil). In addition, this oil purchase adds costs to the operational level because oils from the spot market cost more than the ones from the long-term contracts. Thus, whereas the optimality is the main issue in the single-level formulation, the viability assumes the main role in the integrated approach since it does matter to find the optimal solution of each planning level if there is additional oil purchase. The best integrated solution is the one that eliminates the additional oil purchase at the operational level, which means that the operation has followed the tactical planning and that the tactical solution accommodates the operational uncertainties. So, the integrated approach aims to find a tactical solution that does not lead to additional oil purchases. One way to deal with this problem would be to incorporate more stochastic variables to the tactical model in order to deal with the operational uncertainties in the oil supply. However, this addition would add complexity to the tactical model and the problem would not be completely solved, since the tactical model only distinguishes between product families and not between products within the same family. Therefore, the operational planning integrated to a tactical planning as proposed in this thesis may enable the production to respond effectively to changes in the master plan (tactical planning) in order to increase profit and flexibility in the oil supply chain. Different approaches can be used to integrate the tactical and the operational models, as presented in the section 5.1.

5.1.
Integrated modeling approaches

The integration of information is one of the key features in enterprise-wide optimization and has been achieved with modern information technology tools that allow the sharing and instantaneous flow of information along the various planning levels (Grossman, 2005). Integration is defined as an automation of the transfer of information between planning levels so they may be effectively coordinated (Bodington, 1995). If the flow of information is only from the master problem towards the slave problem, then the approach is named as *hierarchical*. On the other hand, if there is a feedback loop from the slave model back to the master problem in the hierarchical approach, then the approach is *iterative*. If the iterative model is formulated as one single model, then the model is named as *full-space* (Maravelias and Sung, 2009). These three integration modeling approaches are show in Figure 17.

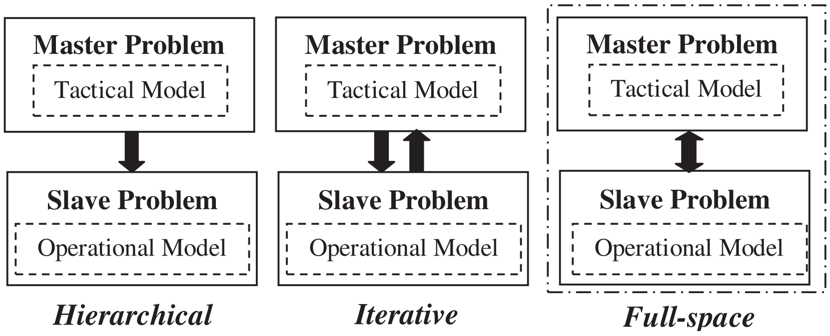

Figure17. Classification of integrated models (based on Maravelias and Sung, 2009)

Solution strategies for the integrated hierarchical, iterative, and full-space problems can be quite different. In hierarchical methods, if a feasible operational plan with the targets assigned by the tactical model does not exist, then a feasible plan in the neighborhood of the infeasible one is sought out so as to have a "globally feasible" solution (Kelly and Zyngier, 2008). To provide more realistic plans, given an infeasible plan, a number of heuristic rules can be applied to obtain feasible operations or a posteriori improvement in the plans obtained (Bassett *et al.*, 1996b; Grunow *et al.*, 2002). Instead of trying to find feasible plans that are in the vicinity of these decisions, iterative methods use mechanisms that allow feedback from one level to the other, enabling the optimization process to go through several iterations to find an overall optimization solution for the integrated planning model. This solution can be achieved by the addition of integer cuts that exclude previously found solutions (Papageorgiou and Pantelides, 1996; Erdirik-Dogan and Grossmann, 2006). Therefore, different solutions can be found by the master problem and evaluated by the lower-level problem. In addition, the master problem can provide an increasing lower bound while the lower-level problem can provide an upper bound. Thus, iterative methods can lead to optimal solutions if the iterations continue until that the gap be closed (Maravelias and Sung, 2009). Full-space models can be solved by standard commercial solvers (Papageorgiou and Pantelides, 1996; Bassett *et al.*, 1996b), by heuristic methods (Reklaitis, 2000; Yan and Zhang, 2007), or by exploiting the model structure via decomposition methods (Kelly and Zyngier, 2008; Chen and Pinto, 2008) or via programming methods such as bilevel programming (Grossman and Floudas, 1987; Clark, 1990; Clark and Westberg, 1983, 1990). The bilevel programming approach refers to optimization models that are constrained by another optimization models. The fact that important mathematical programs such as minimax problems, linear integer, bilinear, and quadratic programs can be stated as special instances of bilevel programs illustrated the importance of these problems (Vicente and Calamai, 1994). One advantage of dealing with bilevel programming problems is that under appropriate objective function and constraint qualifications, the lower level problem can be replaced by its Karush-Kuhn-Tucker (KKT) conditions to obtain an equivalent (single-level) mathematical program.

5.2.
Chapter conclusions

Maravelias and Sung (2009) pointed out the development of computationally effective planning formulations for complex process networks, the communication between the master and slave problems in iterative schemes, and the development of methods that exploit complementary strengths of different solution techniques as the major challenges in integrated planning. In this thesis, accurate solutions regarding the tactical and operational planning models are provided because the refineries were represented in great detail. The application of the two previously presented integration modeling approaches (hierarchical and iterative methods) to the integrated planning of oil refineries is analyzed in the chapter 6.