**WP1 - Supply Chain Network design**

**D1.1 - AN INTEGRATED SET OF METHODOLIGIES AND ALGORITHMS FOR OPTIMIZING DISTRIBUTION, MANUFACTURING NETWORKS AND ENTIRE SUPPLY CHAINS**

Nowadays, due to the rapidly changing economic and political conditions, global companies face a continuous challenge to constantly re-evaluate and optimally configure the operations of their Supply Chain (SC) for achieving key performance indices, such as profitability, cost reduction and customer service. Companies seek to optimize their global SCs in response to competitive pressures or to acquire advantage of new flexibility in the restrictions on world trade. Process industries also follow this trend. The process systems engineering community has been aware of this change and, today, is playing a key role in expanding the system boundaries from chemical process systems to business process systems. The global optimization of a SC network is an extremely complex task. For this reason, SC decisions are typically divided into three decision levels: the operational (scheduling), the tactical (planning), and the strategic (design).

Production planning and scheduling constitute a crucial part of the overall SC decision level pyramid. Planning and scheduling activities are concerned with the allocation over time of scarce resources between competing activities to meet these requirements in an efficient fashion. More specifically, the planning function aims to optimize the economic performance of the enterprise, as it matches production to demand in the best possible way. The production scheduling component is of vital importance as it is the layer which translates the economic imperatives of the plan into a sequence of actions to be executed on the plant floor, so as to deliver the optimized economic performance predicted by the higher-level plan. Overall, recent research is directed toward finding solutions that enable efficient and accurate handling of problems of large size and increasing complexity. However, there remains significant work to be done on both model enhancements and improvements in solution algorithms, if industrially-relevant problems are to be tackled routinely, and software based on these are to be used on a regular basis by practitioners in the field. In addition, new academic developments are mostly tested on complex but relatively small- to medium-size problems. Therefore, the implementation of new production and scheduling approaches in real-life industrial case studies constitutes a challenging task.

In this framework, the thesis titled *“Techniques for the Efficient Solution of Large-scale Production Scheduling & Planning. Problems in the Process Industries”* was presented by Georgios M. Kopanos. Since most academic developments are too distant from industrial environments, the aim of this thesis is to be a step forward in narrowing the gap between planning and scheduling theory and practice by devising efficient mathematical approaches for solving real-life industrial scheduling and planning problems.

An overview of production planning and scheduling, an analysis of existing approaches, methods and tools used throughout this study are first presented. The second part of this thesis is focused on the development of mathematical models for production processes with continuous parallel units. This problem arises in a number of different production environments. In this part, a novel mathematical programming framework is developed based on elegant modeling of the underlying problem. This work addresses challenging problems in a highly complex real-life bottling facility. The proposed framework addresses appropriately important changeover aspects such as changeover carryover and crossover, thereby leading to solutions resulting in higher utilization of resources.

The third part is focused on semicontinuous industries, which combine continuous and batch operation modes in their overall production process. First, a mathematical programming framework and a solution strategy are presented for the optimal production scheduling of multiproduct multistage semicontinuous process industries. A real-life ice-cream production facility has been considered. Second, a general mathematical programming approach is developed for the resource constrained production planning problem in semicontinuous processes. This work has been motivated by a challenging problem in food processing industries related to yogurt production lines, where labor (i.e., the number of available workers) constitutes the limited resource constraint. Third, a novel mathematical formulation for the simultaneous optimization of production and logistics operations planning in large-scale single- or multi-site semicontinuous process industries is proposed. Alternative transportation modes are considered for the delivery of final products from production sites to distribution centers, a reality that most of the current approaches neglect. Two industrial-size case studies for a real-life dairy industry have been solved to optimality.

The forth part of the thesis deals with scheduling in batch processes. First, a real-life multiproduct multistage pharmaceuticals production facility is considered. A systematic two-stage iterative solution strategy, based on mathematical programming, has been developed to address this problem. Additionally, a new precedence concept has been developed in order to cope with objectives containing changeover issues. A salient feature of the proposed approach is that the scheduler can maintain the number of decisions at a reasonable level, thus reducing appropriately the solution search space. This usually results in manageable model sizes that often ensures a more stable and predictable optimization model behavior. Finally, a preliminary two-layered decomposition method to the batch process scheduling problem in multipurpose production plants is developed. The procedure is tested on published problem instances of a broadly-studied benchmark scheduling problem that considers a polymers production plant.

The objective of this thesis has been to establish mathematical programming techniques and solution approaches for the efficient solution of complex process scheduling and planning problems. For this reason, a number of real-life case studies, contemplating representative sectors and significant process industries (chemical, pharmaceuticals, food and beverage industries), have been addressed and solved by new mathematical programming frameworks devised in this thesis.

* Part I identifies the major challenges to be addressed through an extensive state-of-the-art review. Although production planning and scheduling has become the subject of intensive research, an attentive review reveals the areas where new contributions are needed for a major impact in real-world applications. In addition, the fundamental theory and concepts behind the methods and tools used throughout the thesis is briefly described.
* Part II deals with continuous processes. More specifically, an industrial case study considering the simultaneous planning and scheduling problem in the bottling stage of a real-life beer industry, producing hundreds of final products, has been addressed. A special feature of the problem in question is that final products can be classified into product families. The grouping into families is based on various criteria, including product similarities, processing similarities, and/or changeover considerations. A hybrid discrete/continuous-time mathematical approach to the simultaneous production planning and scheduling of continuous parallel units producing a large number of final products that can be classified into product families has been developed. In contrast with previous research works, a more general case has been considered based on:
  + Product families.
  + Short planning periods that may lead to idle units for entire periods.
  + Changeovers spanning multiple periods.
  + Maintenance activities.

The proposed approach also addresses appropriately aspects such as changeover carryover and crossover, thereby leading to solutions with higher utilization of resources. Very good solutions to problems with hundreds of products can be obtained within 5 CPU min, while optimal solutions can also be found in reasonable time. Furthermore, the proposed formulation yields solutions which are substantially better than the ones obtained using commercial tools, suggesting that MIP methods can be used to address large-scale problems of practical interest.

* Part III deals with food process industries that combine batch and continuous operation modes in their overall production process. A multiproduct multistage semicontinuous ice-cream production facility is considered. A new MIP framework and a solution strategy have been presented for the optimal production scheduling of this production facility. Although, the proposed mathematical formulation is well-suited to the ice-cream production facility considered, it could be also used, with minor modifications, in scheduling problems arising in other semicontinuous industries with similar processing features. The overall mathematical framework relies on an efficient modeling approach of the sequencing decisions, the integrated modeling of all production stages and the inclusion of strong valid integer cuts in the MIP formulation. The simultaneous optimization of all processing stages increases the plant production capacity, reduces the production cost for final products, and facilitates the interaction among the different departments of the production facility. The proposed MIP formulation and the proposed solution methodology results in very low computational times for the several problem instances solved.

Moreover, a multiproduct semicontinuous yogurt production facility, where labor (i.e., the number of available workers) is a limited resource, is studied. Production planning in semicontinuous processing plants typically deals with a large number of products, however many products appear with similar characteristics, and therefore final products can be grouped into product families. Thus, the production planning problem under question could be partially focused on product families rather than on each product separately. A general MIP approach has been presented for the resulting resource-constrained production. Quantitative as well as qualitative optimization goals are included in the proposed model. The definition of product families significantly reduces the size of the underlying mathematical model and, thus, the necessary computational effort without sacrificing any feasibility constraints. A number of cases studies, also considering unexpected event scenarios (i.e., workers absence, and products orders modifications), have been solved in reasonable computational time, considering production and logistics operations planning in large scale single- or multi-site semicontinuous process industries. A novel mixed discrete continuous-time mixed integer programming model, based on the concept of families of products, for the problem in question has been developed. A remarkable feature of the proposed approach is that in the production planning problem timing and sequencing decisions are taken for product families rather than for products. However, material balances are realized for every specific product, thus permitting the detailed optimization of production, inventory, and transportation costs. Additionally, alternative transportation modes are considered for the delivery of final products from production sites to distribution centers, a reality that most of the current approaches totally neglect. The efficiency and the applicability of the proposed approach is demonstrated by solving to optimality two industrial size case studies, for an emerging real-life dairy industry. It is worth noting that despite the complexity of the problems addressed, the proposed approach appears a remarkable computational performance.

* Part IV deals with scheduling in batch processes. A real-life multiproduct multistage pharmaceuticals scheduling problem is considered. A systematic two-stage iterative solution strategy, based on mathematical programming, has been developed. More specifically, the proposed solution strategy consists of a constructive step, wherein a feasible and initial solution is rapidly generated by following an iterative insertion procedure, and an improvement step, wherein the initial solution is systematically enhanced by implementing iteratively several rescheduling techniques; based on the mathematical model. A salient feature of the proposed approach is that the scheduler can maintain the number of decisions at a reasonable level thus reducing appropriately the search space. This usually results in manageable model sizes that often guarantees a more stable and predictable optimization model behavior. Several challenging large-scale scheduling problem instances, considering alternative optimization goals, of a pharmaceuticals production facility have been solved. Also, it is worth mentioning that a new precedence concept (i.e., the unit-specific general precedence) has been developed in order to cope with objectives containing changeover issues.

Finally, a two-layered decomposition methodology to the batch process scheduling problem in multipurpose production plants has been developed. In the first level, an approximate scheduling model derived from the detailed STN-based time-indexed scheduling formulation is solved; the model partially relaxes the allocation of task instances to processing units details of the full scheduling formulation. In the second level, the output of the approximate scheduling problem is used to provide batching targets for the detailed scheduling model within an iterative decomposition scheme. The procedure is tested on published problem instances of the Westenberger-Kallrath benchmark scheduling problem considering a polymers production plant. Despite the promising results, future work is needed in order to further improve the performance of proposed decomposition strategy.