Rolling Horizon Approach for Production - Distribution Coordination of Industrial Gases Supply-Chains

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An industrial gases supply-chain coordinates production/distribution decisions at multiple plants/depots while satisfying several customer demands. Plants operate air separation units, which feature high electricity consumption, to produce gaseous and liquid products. Distribution is carried out by pipeline for gaseous products and by truck for liquid products. For truck distribution, multiple depots are considered. Moreover, trucks at a given depot can deliver product from multiple sources. In order to ensure customer storage replenishments, product can be purchased from alternative sources. As the number of sources and customers increase, the selection of the possible routes to be included in the formulation becomes a critical issue.

Production decisions include production modes and rates at each plant, with varying efficiencies and power consumptions. To handle electricity price fluctuations during the day a peak/off-peak pricing scheme is considered. The main distribution decisions include the association of vehicles with routes at each time period. Besides, distribution capacity depends on the inventory levels of liquid products at each plant. A detailed distribution management including availability of trucks, trailers, and drivers, and truck load, travel, and delivery times can be indirectly considered. At the supply-chain level, production and distribution decisions must be coordinated to fulfill several customer demands, local demands, and guarantee a safety stock in the inventory levels while minimizing the overall cost. Fixed customer demands based on forecast data or consumption profiles are considered. Consequently, inventory management plays a key role to guaranty the replenishment of storage tanks at customer locations. Main model assumptions: i) two time periods per day (peak/peak off) are considered; ii) trucks do not visit more than 4 customers in a single delivery; iii) maximum and minimum inventory levels; iv) truck availabilities and capacities.

This work further elaborates on a mixed-integer linear programming (MILP) formulation to minimize the overall cost of production and distribution of industrial gases supply-chains. While previous work provides optimal production-distribution decision making[1], the computational effort required to solve the problem is still an issue to consider when industrial size examples are studied. This issue is mainly due to the combinatorial nature of the problem at the distribution side, where multiple trucks are used to pick up products and visit multiple locations at each time period. This work proposes a rolling horizon (RH) framework to enhance the solution of production-distribution coordination problems for large-scale industrial gases supply chains.

The case studies considered result in large-scale optimization problems. Being an effective decomposition technique, the rolling horizon approach has been widely studied in literature.[2,3] It provides a series of small-scale optimization models that reduce the computational burden of the full-size problem.[4] The RH method divides the time horizon into a “detailed time block” and an “aggregated time block” and solves a set of sub-problems reducing the complexity of the model. The “detailed time block” uses the representation of the original model, while a simplified model must be provided for the “aggregated time block”. RH has been applied in a number of supply-chain management problems. Ierapetritou et al. (2010)[3] proposed a new heuristic method to improve the solution quality of the rolling horizon method for

integrated planning and scheduling optimization. The heuristic method is based on the development of a production capacity model through a parametric programming approximation. Another interesting approach to reduce the computational effort in strategic supply-chain planning models is presented by Kostin et al. (2011).[5] Based on the RH approach they developed a new heuristic method where some of the integer variables are considered as continuous, finding that the relaxation of the integer variables is tight. This means that the solution of the relaxed model is very close to the optimal solution of the original problem.

This work describes a rolling horizon framework in which two approaches for the "aggregate time block" are studied. The first one relies on a relaxation of the integrality condition of binary variables. The second one consists of aggregating the detailed distribution by considering direct shipping with unlimited trucks availability to satisfy customer demands. Both approaches, which provide rigorous lower bounds, are studied under a forward RH scheme. The results of the proposed framework show a significant reduction in the computational burden for up to a factor of 7 times faster, while improved solutions are obtained compared to a full space solution which cannot be solved to optimality. These solutions provide higher coordination among plants/depots to satisfy a common set of shared customer demands. Additionally, a comparison between the rolling horizon heuristic and a Lagrangean Decomposition of the full-size problem is presented.

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