Integrated Planning of Oil Products Blending and Multimodal Distribution

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Summary

Planning blending operations has become a critical task for petroleum refiners. The physical mixture of refined hydrocarbons permits to produce finished products under increasingly stringent specifications. Blending of gasoline and distillates is accomplished by mixing proportionate amounts of different oil fractions. Moreover, additives including octane enhancers, metal deactivators, anti-oxidants, anti-knock agents, gum and rust inhibitors, are added to provide specific properties not inherent in hydrocarbons [1]. For this purpose, the refinery infrastructure usually comprises component and product tanks as well as blending equipment with multiple operational features, like limited production rates and finite capacities.

In turn, refined products distribution is a very challenging problem involving multiple transportation modes. Oil pipelines are extensively used by petroleum refiners for carrying large quantities of refined petroleum products over long distances on land [2]. Ships are the other major mode for the primary transportation of oil products from refineries to distribution centers or harbors. Then, minor pipelines, trains or barges deliver oil products from distribution centers to petrochemical plants, airports or hubs, while trucks are the most common choice for the last-mile distribution, from transportation hubs to gas stations or small customers.

Scheduling pumping and delivery operations in multiproduct pipelines is a complex logistic problem. Limited tank capacities, delivery dates and refinery production plans are problem conditions to be taken into account. But one of the most challenging issues is the interface generation. As different products are shipped through the same line, usually without separation devices, a product mixture is formed in the interface of two consecutive batches. The product contamination strongly depends on the ordered pair of species put in contact. Optimizing the size and sequence of product batches transported through pipelines requires accurate models and efficient computational tools [3].

Besides, the optimal planning of other transportation modes (ships, trains and trucks) seeks to determine the set of delivery routes for a fleet of vehicles, commonly housed at depots [4]. Every vehicle route must start and finish at the assigned depot, each customer is to be visited by at least one of the vehicles, and vehicle capacities must not be exceeded. The objective is usually the minimization of the travel cost, preventing from delays in demand fulfillment.

To reduce refinery operation costs, blending operations should be effectively integrated to final product distribution, in order to fulfill customer demands with the right product at the right

time. The short-term planning of both blending and delivery operations becomes a complex task due to the need of managing a large number of orders, delivery time-windows, multiple transportation modes, alternate blending equipment, limited number of product tanks, quality specifications, and variable product recipes. Manual and non-exact planning generates inefficient schedules that result in higher production costs, quality giveaways, larger inventories, and delivery demurrages. Optimization techniques such as mixed-integer linear programming (MILP) models can be used to generate better schedules that aim to minimize operation costs and improve customer satisfaction. Recently, MILP approaches based on unit-specific, slot-based representations that mimic the production sequence have been proposed. However, even simplifying the delivery plan representation, the CPU time required to obtain feasible solutions is extremely large, and the usefulness of such tools in a real-world environment is actually low [5,6,7].

To overcome this limitation, we develop a comprehensive strategy based on a more efficient MILP formulation [8]. The new computational tool is able to find an integrated short-term plan of blending and distribution tasks, simultaneously optimizing the operation of all the transportation modes. The proposed model makes use of efficient sequencing and inventory tracking constraints, which permits to optimally determine: (a) the number of batches of each product to be processed, the operation times and production rates; (b) the recipe for each batch; (c) the batch-blender allocation, sequencing and timing; (d) the assignment of product batches to storage tanks; and (e) the multimodal delivery plan to timely fulfill customer orders over the planning horizon.

The major elements of the model are: (i) blending components and tanks, (ii) blenders, (iii) storage tanks for the blended products, and (iv) single-product orders to be fulfilled over the planning horizon and their delivery time windows. The model is based on the following assumptions:

(a) Each order should be served through a certain transportation mode, connected to a limited number of finished product tanks.
(b) Blending components and final products have known quality specifications given by the property indices, such as octane number and sulfur index. Each blend component is characterized by constant properties, while blended products properties should be within the desired interval.
(c) Blenders operate in a semi-continuous mode, mixing several component flows in different proportions to get a batch of blended product.
(d) Similar to previous works [6], linear mixing correlations on either volume or weight basis are assumed to determine the product properties.
(e) Since non-identical blenders are available, the number of batches of each product to be processed is initially unknown [9].
(f) Component tanks can receive and discharge flows at the same time.
(g) A single product can be hold in each tank during the time horizon.
(h) The delivery of a product batch from the assigned tank can start only if its production run has finished and is completely unloaded into the tank.

Linear model constraints are destined to: (1) allocate product batches to blenders, (2) determine the sequence of product batches processed in each blender, (3) fulfill customer orders, (4) coordinate product deliveries, (5) monitor inventories of components and finished products at refinery tanks, (6) control refined product properties according to specifications, and (7) identify product changeovers at each blender. Finally, the objective function aims to minimize the sum of production, demurrage and transitions costs.

Compared to previous works, results show drastic reductions in the CPU time, of up to three orders of magnitude in real-world problems of the oil industry. This alternative formulation is able to find the optimal planning of blending and distribution operations at modest CPU times, thus satisfying a challenging requirement of the modern refining industry. The model efficiency relies on very tight relaxations, with integrality gaps below 1%.

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