# Logistics optimization for dispositions and depooling of product distillates in oil-refineries: closing the production scheduling and primary distribution gap

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## Abstract

At the edge of the manufacturing of crude-oil distillates into refined final products, the production scheduling and primary distribution gap can be reduced by optimizing production rundown switches of dispositions of distillates in a mixed-integer linear model (MILP) considering discrete time-steps of days, shifts or hours for a delivery horizon of weeks or months. From the process network down to the product distribution side, there are definitions on the assignments, allocations and amounts of distillates to be dispatched downstream. Other challenges involve logistics and quality aspects in further process-shops and blend-shops considering diverse tank farms and various transport modes for the distribution. However, such integration of the refining process and tank storage systems can become intractable for industrial-sized problems with complex scheduling configurations considering time-varying rundown supply rates, product demands and pricing. For this, we propose to model the dispositions of distillates using unit-operations as modes of transportation from the distillation sources to the tanks of process-shops and blend-shops for downstream processing and blending before the primary distribution. Additionally, by solving with pooling (groups of tanks) first then post-solve to depool by disaggregating the pooled solution, the determination of the distillate dispositions to tank assignments is facilitated given that scaling to industrial-sized cases without tank aggregation is complicated as highlighted in the examples. Better prediction of the operations scheduling by using small discrete time-steps within a planning horizon allows opportunities for exploring the contract and spot market plays of the finished products.

**Keywords**: crude-oil distillates, product scheduling, rundown switches, depooling, MILP.

## 1. Introduction

In the process industries with a wide variety of different quality feeds and products, especially in oil-refining and petro-chemicals manufacturing, the high-performance and complex refining of crude-oils into products can be achieved, for example, considering integrated approaches of the following subsystems: a) raw material or feed procurement, shipping, unloading, storage, dieting and charging, b) combined operations of process-shops and blend-shops, c) management of intermediate and final product inventories, d) sales and distribution of refined products.

From the monthly and weekly procurement planning cycle up to the daily and hourly production scheduling from crude-oils to distilled products or distillates, an enterprise-wide optimization (EWO) strategy can feedback decisions from a lower to an upper level for a new search of a solution, updating lower level results as targets and reducing time-grids in upper level re-optimizations (Menezes et al., 2017). By reducing the procurement time-step from a month to a week in the iterative optimization steps, this can potentially avoid long storage periods of raw materials or even their premature processing to maintain the plant feed. However, there are many challenges to develop such an EWO approach from the scheduling of product process-shops and blend-shops to the primary distribution management that typically evolves from time-steps of an hour, shift, day to those found in planning considering weeks, months and quarters.

First, to efficiently maintain the production for downstream process units, tanks or any modes of transport, a wide scheduling optimization shall determine production rundown switches in days, shifts or hours (small-buckets) for a delivery horizon of weeks or months (big-buckets), yielding models with hundreds or thousands of time-periods. Therefore, despite the quality and nonlinear aspects in the production network, which in turn can still be modified in downstream process-shops and blend-shops, a logistics optimization primarily must find the dispatching routes or dispositions of the distillates using a mixed-integer linear (MILP) model. This quantity and logic programming involves variables of networked amounts of flows and holdups, assignment of dispatching routes modeled as modes of operations, constraints for running-gauge and standing-gauge tanks of intermediate and final inventories, operations of blend-shops, multiproduct liftings via multiple mode of transport such as trucks, pipelines, ships, rails, etc.

Second, the complex scope of the MILP logistics optimization for disposition of distillates may count on simplifications to be solvable. We address the use of a depooling heuristic to facilitate the scaling to industrial-sized cases. Pooling and depooling is shown to help manage the temporal and structural degeneracy and symmetry of stocking and dispatching the intermediate tanks with distillates. Logistics pooling or group of tanks to depooling of individual ones is determined in a post-optimization step and sometimes referred to in industry as tank rotation, swinging or round-robin. The assignment of each disposition to the multiple tanks of the pooled group is performed before the processing and blending operations are executed. If an infeasibility occurs in the depooling sub-problem, then a modification to the filling (stocking) and/or drawing (dispatching) side of the tank flows can be made and the pooled problem re-run.

By solving such complicated logistics problem with a discrete time-step of around hours for a month as the time horizon, makes the production-distribution business more competitive since both fixed contracts and variable spot markets of feeds and products compete and complement each other. It maintains the balance between sustainability and profitability, the former via long-term contracts and the latter relying on short-term opportunities in the spot markets. Finally, we highlight examples varying the topology (unpooled vs. pooled) for some distillate inventories. They are solved for 1, 2 and 4 hours as time-step using the best MILP solvers in the market considering both feasibility and optimality as their focus since there is a balance between finding new feasible solutions and proving that the current solution is optimal. Although we expect a faster first solution in the feasibility focus, the optimality one maybe faster overall as seen in the examples.

## 2. Scheduling and primary distribution of products

In the logistics mixed-integer linear programming (MILP) problem (*P*), the objective function (1) maximizes the gross margin of product revenues considering the production scheduling and distribution network represented in Figure 1, which is constructed in the unit-operation-port-state superstructure (UOPSS) formulation (Kelly, 2005; Zyngier and Kelly, 2012). The UOPSS objects are: a) unit-operations *m* for sources and sinks of perimeters (◇), tanks (△) and continuous-processes (⊠) and b) the connectivity or routes involving arrows (➝), in-port-states $i$ (○) and out-port-states *j* (⊗). Unit-operations and arrows have binary and continuous variables (*y* and *x*, respectively).

The semi-continuous constraints in Eq. (2) control the networked quantity-flows for the connections $x_{j,i,t}$, the throughputs or charge-sizes of the unit-operations $x_{m,t}$ (except tanks) and tank holdups, inventory levels or lot-sizes $xh_{m,t}$, where $x_t$ and $y_t$ are generic continuous and binary variables. Eq (3) imposes that the sum of the connected arrows arriving in the inlet-ports *i* (or mixers) of unit-operation *m* ($m \notin M_{TK}$) are bounded by their throughputs (flows). Similarly, in Eq. (4) the sum of the arrows leaving from the outlet-ports *j* (or splitters) of *m* ($m \notin M_{TK}$) must be between bounds of their throughputs. The quantity balance of inventory or holdup for unit-operations of tanks ($m \in M_{TK}$) in Eq. (5) considers initial inventories $xh_{m,t-1}$ and inlet and outlet streams of the tanks. Eq. (6) is a material balance in blenders $M_{BL}$ to assure that there is no accumulation of material in these types of units. In Eq. (7), for all physical units, at most one unit-operation *m* (as $y_{m,t}$ for procedures, modes, dispositions or tasks) is permitted in *U* at a time *t*. The remaining logistics calculations can be found in Kelly et al. (2017). Unit-operations *m* for tanks, blenders, and products belong, respectively, to the sets $M_{TK}$, $M_{BL}$, and $M_P$. The port-states $j'$ and $i''$ represent upstream and downstream ports connected, respectively, to the in-port-states $i$ and out-port-states *j* of unit-operations $m$. For $x \in \mathbb{R}^+$ and $y \in \{0,1\}$:

$$(P)\ \ Max\, Z = \sum_t \sum_{m \in M_P} price_{m,t}\, x_{m,t} \tag{1}$$

$$\bar{x}_t^L\, y_t \le x_t \le \bar{x}_t^U\, y_t \ \ \forall\, t \tag{2}$$

$$\frac{1}{\bar{x}_{m,t}^U} \sum_{j'} x_{j',i,t} \le y_{m,t} \le \frac{1}{\bar{x}_{m,t}^L} \sum_{j'} x_{j',i,t} \quad \forall\, i,m,t \tag{3}$$

$$\frac{1}{\bar{x}_{m,t}^U} \sum_{i''} x_{j,i'',t} \le y_{m,t} \le \frac{1}{\bar{x}_{m,t}^L} \sum_{i''} x_{j,i'',t} \quad \forall\, j,m,t \tag{4}$$

$$xh_{m,t} = xh_{m,t-1} + \sum_{j'} x_{j',i,t} - \sum_{i''} x_{j,i'',t} \ \forall\, m \in M_{TK}, t \tag{5}$$

$$\sum_i \sum_{j'} x_{j',i,t} = \sum_{i''} x_{j,i'',t} \ \ \forall\, m \in M_{BL}, t \tag{6}$$

$$\sum_{m \in U} y_{m,t} \le 1 \ \ \forall\ t \tag{7}$$

The flowsheet in Figure 1 shows an example of a typical crude-oil refinery network for the production and distribution of medium to heavy final fuels considering given amounts of distillates produced in two crude-oil distillation units CDU1 and CDU2. The distilled kerosene (KERO), light gasoil (LGO) and heavy gasoil (HGO) streams can be dispatched to feed tanks for processing in units such as hydrotreaters, dryers, blenders or directly to a finishing tank for commercialization. The transport of products considers pipelines, trucks, ships, rails and other local market deliveries to supply the multiple consumers under precise product demands.

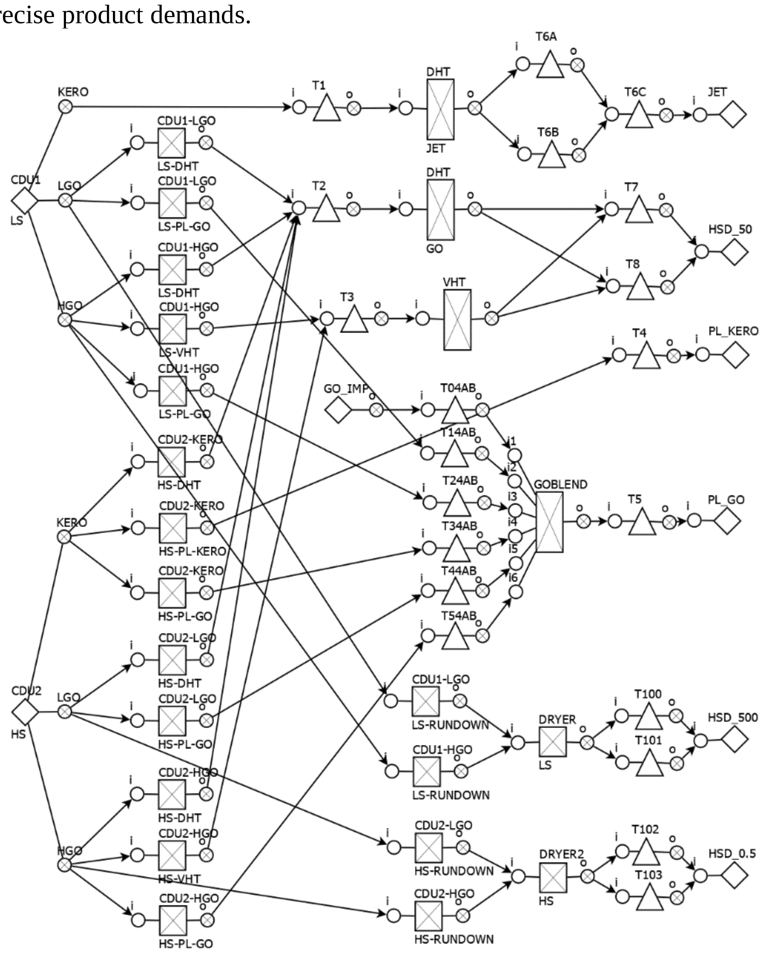


Figure 1. Medium to heavy distillates: production and distribution scheduling flowsheet.

In Figure 1, DHT-JET and DHT-GO represent the same physical hydrotreater DHT with JET (Jet Fuel) and GO (Gasoil) as modes of operation. VHT is a hydrotreating unit for HGO, the dryers of light and heavy HGO are the units DRYER and DRYER2 and the blender of HGO is the unit GOBLEND. The dispositions of the distillates in Figure 1 show: a single mode for KERO from CDU1, 3 modes of operations for CDU2-KERO and LGO from both CDU1 and CDU2 towers and HGO from both CDU1 and CDU2 with 4 modes. Transformations in DHT and VHT are disregarded, although a reduction on the yields of the medium distillates are expected by the secondary carbon chain cracking and the replacement of heteroatoms and metals by hydrogen. Both T2 and T3 in Figure 1 are pooled tanks with 5 and 2 aggregated tanks, respectively.

## 3. Dispositions and depooling of networked amounts or allocations

Figure 1 shows the dispositions of the distillates as modes of operations for KERO, LGO and HGO streams. However, to avoid degeneracy and symmetry among the assignments of the dispositions to their possible connected tanks, a *pooled* problem can be solved first and the disposed amounts of the distillates can be considered as sources (e.g., CDU1-LGO) in a *depooling* step of the downstream processing unit-operations (e.g., DHT-GO), as seen in Figure 2 for 5 physical tanks in the depooling of T2. Additional constraints to the depooling are related to multi-use of the source and sink ports, fill-draw delays and switching-when-full, switching-when-empty, etc. (Zyngier and Kelly, 2009).

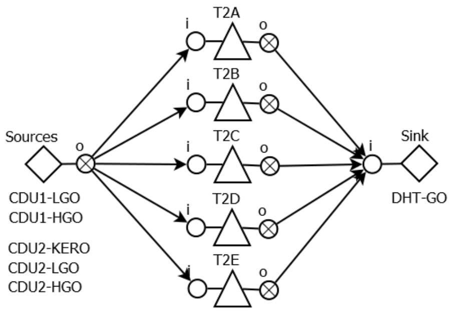


Figure 2. Depooling sub-network for tank T2 in Figure 1.

## 4. Examples

The example in Figure 1 is performed in the structural-based UOPSS framework found in the semantic-oriented modeling and solving platform *IMPL* (Industrial Modeling and Programming Language) from Industrial Algorithms Limited using Intel Core i7 machine at 3.70 GHz (in 8 threads) with 64GB of RAM. The logistics optimization for the proposed MILP in a time-horizon of 31 days with 1, 2 and 4 hours as time-step (744, 372 and 186 time-periods, respectively) is solved using the latest version of CPLEX (v 12.71) and GUROBI (v 7.5.1). As seen in Table 1, the fastest solution for 1h time-step without pooling or aggregation of the tanks T2 and T3 (the unpooled problem) is optimized with GUROBI in about one half of an hour where its pooled problem is solved in around 2 minutes. For the pooled cases, the post-optimized sub-problems for depooling of T2 and T3 are solved within seconds with no infeasibilities. The depooling problem of T2 (Figure 2) has (in thousands) 13.6 equations and 8.2 continuous and 7.4 binary variables.

Table 1. Statistics of the problems for 1, 2 and 4 hours as time-step (at 1% MILP gap).

| Topology | Focus | CPU (min) | | | | | | Equations | Continuous/ Binary Variables |
|---|---|---|---|---|---|---|---|---|---|
| | | CPLEX | | | GUROBI | | | (in thousands) for 1h | |
| | | 1h | 2h | 4h | 1h | 2h | 4h | | |
| unpooled | feasibility | 333.3 | 65.4 | 23.9 | 33.5 | 23.0 | 1.2 | 380.3 | 125.0 / 112.9 |
| | optimality | 785.3 | 190.0 | 32.2 | 29.1 | 18.5 | 1.0 | | |
| pooled | feasibility | 60.7 | 18.6 | 4.1 | 4.3 | 2.8 | 0.7 | 304.7 | 107.6 / 85.8 |
| | optimality | 35.3 | 112.4 | 0.8 | 1.7 | 2.0 | 0.4 | | |

Figure 3 shows the dispositions of the CDU1-HGO considering the possible destinations.

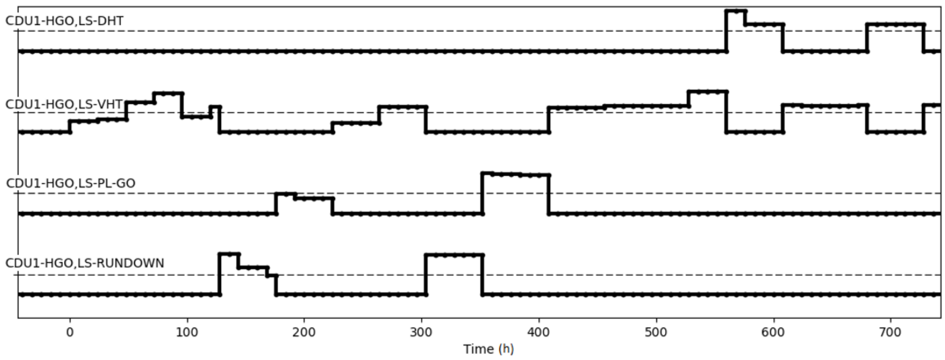


Figure 3. CDU1-HGO dispositions throughout the network.

## 5. Conclusions

A wide scope and scale for mapping of flows and holdups of intermediate and final products are determined in our proposed logistics optimization for the oil-refinery production- and demand-chains specific to distillates. This can potentially guide operational and marketing / sales teams to explore both contract and spot market opportunities on a day-by-day business basis taking advantage of a short-term hourly production-based scheduling solution within a planning perspective. At the edge of the modeling and solving capabilities, the aggregation, grouping or pooling of tanks and its disaggregation or depooling into individual and detailed tank assignments, has been shown to significantly reduce the computing time without any or limited loss in the accuracy of the scheduling results.

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