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Rescheduling of Medium Term Pipeline Operation with Tank Farm Inventory Management

Susana Relvas,[a,c] Ana Paula Barbosa-Póvoa,[b] Henrique A. Matos,[a] João Fialho,[c]

[a]*DEQB-IST, Av. Rovisco Pais 1049–001 Lisboa, Portugal, susanaicr@ist.utl.pt; henrimatos@ist.utl.pt*
[b]*CEG-IST, Av. Rovisco Pais, 1049-001 Lisboa, Portugal, apovoa@ist.utl.pt*
[c]*CLC, EN 366, km 18, 2050 Aveiras de Cima, Portugal , joao.fialho@clc.pt*

Abstract

Oil supply chain is a complex network of several nodes, with trading of information and products' flow. Any decision supporting tool combining knowledge from strategic, tactic to operational management levels is a benefit for decision makers. Nevertheless, the tradeoff between the system complexity and the tools development must be accounted for. This work focuses on the establishment of a continuous time and volume MILP (Mixed Integer Linear Programming) model to describe a multiproduct pipeline operation with an associated outbound storage tank farm. The model allows not only the definition of an initial operating schedule but also is able to deal with the dynamic nature of the operation accounting for rescheduling situations. Real world data from CLC (a Portuguese company) validate the model formulation.

Keywords: Multiproduct pipeline, storage tank farm, rescheduling, MILP

1. Introduction

Pipelines are widely used in the oil supply chain to connect ports to refineries or refineries to local markets. This type of equipment is a cost effective and reliable method to transport large volumes of products over long distances. The pipeline usually supplies local tank farms where the products are stored and subjected to quality tasks before becoming available to the final clients. The major challenge when studying such systems is its representation as an adequate tool that can help the decision making process associated with the systems operations where all the important interactions are accounted for.

Published works on this area make use of discrete [1,2] or continuous mixed integer formulations [3], where the focus is on the pipeline system and where no emphasis is made on the tank farm operation. Therefore, important operating interactions within the supply chain entities have being neglected such as restrictions imposed on the pipeline operation due to the outbound storage limitations (e.g capacity constraints).Furthermore, the dynamic nature of such systems has not yet been addressed in previous works, which often leads to the need of applying rescheduling policies to the pipeline operation.

The main objective of this work is to overcome some of these limitations. A system formed by a pipeline and an outbound farm tank is modeled. The model is used to address rescheduling situations where different real events are modeled. The model is based on the formulation proposed by Relvas *et al.* [4], that was generalized to include variable flowrate, variable settling period by product and pipeline stoppages.

The real scenario of CLC - Companhia Logística de Combustíveis, illustrates the approach. CLC distributes refinery's products in the central area of Portugal.

2. Problem Statement and Mathematical Formulation

The system comprises a pipeline that connects a refinery to a single tank farm. At the destination, each product has a set of tanks of fixed service. Common operation is to fill up completely one tank, with minimum interfaces, accomplish the required settling period and then deliver the product to clients. Given:

1. The pipeline data and the matrix of possible transportation sequences;
2. The available storage capacity of each tank and the minimum settling period by product;
3. Pumping rate limits and time horizon extent;
4. The initial conditions: inventory levels and lots inside the pipeline;
5. The daily products' demand.

The solution comprises a pipeline schedule (including sequence, volume, flowrate, and timing issues) that meets tank farm inventory management objectives. Lots reception at pipeline end and settling periods are controlled to avoid stock out, meeting daily compulsory clients' demands.

Each scenario is optimized under an operational direction that minimizes medium flowrate and maximizes pipeline usage. This multiobjective function uses unitary weights for both normalized terms.

The model formulation uses continuous time and volume scales (see Relvas *et al.* [4] where some of the bellow features are modeled.

2.1. Products' Sequence

The pipeline operation is constrained by the occurrence of forbidden products sequences. Taken into account these restrictions the model decides on the optimal products sequence.. This corresponds to a free sequence model that, although general, is hard to solve in some situations. In order to improve the model performance alternative conditions were explored based on real plant procedures that do not restrict the model operation. As a result both fixed and mixed sequences were modeled. For the mixed sequence, some positions are left open for model decision where the adequate products are inserted.

2.2. Daily clients' demands

Clients provide their demands usually on a daily basis. This model is able to process daily demands. However it is necessary to transform discrete information into continuous information. The model uses binary variables that allocate each day to a continuous time interval, as in the scheme of Figure 1.

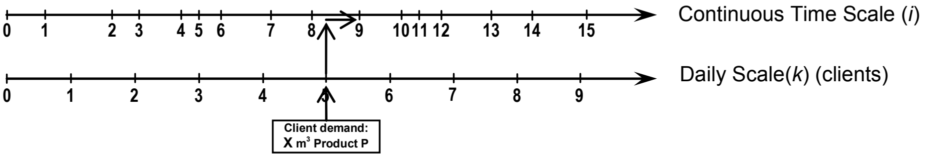

Figure 1 – From discrete to continuous clients' information

2.3. Tanks representation

The model currently manages tanks in an aggregated manner. In the tank farm, each product is stored in a group of fixed tanks. The total capacity available for each product is aggregated into a single tank.

3. Rescheduling

Real world systems are constantly facing unpredicted situations that motivate rescheduling over the current operational plan. Six possible causes for rescheduling are presented in Table 1, which have been typified through the analysis of real plant occurrences.

The methodology developed receives the current plant plan and new data that may lead to plan modifications. Based on these performs the plan revision where more than one causes for rescheduling can be accounted for simultaneously. Past and present occurrences are fixed and possible changes are incorporated into future operation. The objective function considers not only the plan objective but also penalization terms that reduce deviations from the initial plan, on binary variables (for sequence and lot volume allocation).

Table 1 – Rescheduling situations

	Situation	Description
S1	Clients' demands	Adjustments on demands on a periodic basis, e.g. weekly.
S2	Imposition on products' sequence	Due to economical or inventory management reasons (at the refinery or tank farm).
S3	Unpredicted pipeline stoppages	Due to product shortage at the refinery or operational conditions (at the refinery or tank farm).
S4	Lots' volumes changes	Mainly due to refinery imposition (e.g. product shortage).
S5	Flowrate adjustments	Mainly due to economical reasons or to answer quickly to an unexpected client demand.
S6	Variation on maximum storage capacity	Due to tanks' maintenance, which take place when the tank is empty.

4. Results

The model was implemented in GAMS 22.2 and solved with CPLEX 10.0, on a Pentium D820 with 2 GHz RAM. The plan is performed for a 31-day time horizon (July 2006). Flowrates can vary from 500 to 600 v.u./h and a fixed sequence is assumed. Table 2 describes the rescheduling revisions implemented throughout this month, based on the real occurrences at CLC's facilities.

Four plan revisions were analyzed. These cover the six situations proposed in Table 1. In revisions 2 and 4 more than one rescheduling occurred.

Table 2 – Rescheduling revisions on a medium term time horizon at CLC's facilities

	Real Occurrences at CLC's site
R0	Initial Plan, built before the scheduling horizon beginning
R1	Imposition on products' sequence: including exactly one lot of product P3. $T^{revision} < 0$ h (S2)
R2	New clients' demands after week 1 ($T^{revision} = 144$ h) and 13 h of pipeline stoppage at $T = 190$ h, imposed by refinery due to product shortage (S1, S3)
R3	Decrease on storage capacity of product P5 on 1720 m^3 at $T = 480$ h, $T^{revision} = 400$ h (S6)
R4	Adjustment on lot 34 (of product P5) flowrate (later pumping, not before than 675 h) and lot 32 (of product P2) volume change (from 16000 to 13500 m^3), $T^{revision} = 600$ h (S4, S5)

Table 3 summarizes model performances for the 5 scenarios. Stopping criteria are either a relative gap lower than 5% or 7200 CPU seconds of computation. At each computation's end, CPLEX's polishing option is used for 15 seconds.

Model size is kept throughout all scenarios, but the amount of information from previous runs grows with the scenario number and therefore fixed decisions are considered. This results in drastic reductions on the computation time. Higher values on the objective function (OF) indicate higher volume of changes between current and previous plans (penalized in additional OF terms). Main discrepancies on model sizes are related to formulations to cope with systems' changes. Final inventories for each scenario as well as some indicators concerning the system operation, such as medium flowrate and overall pipeline usage, are presented in Table 4.

Table 3 – Model performance through the rescheduling procedure

Revision	**R0**	**R1**	**R2**	**R3**	**R4**
# Continuous Variables	25 838	25 840	25 871	25 819	25 808
# Binary Variables	6 206	6 196	5 922	5 660	5 516
# Equations	46 513	46 516	47 246	46 368	46 299
# Nodes Explored	4 191	4 107	1 120	21	1
# Iterations	364 279	3 468 976	38 800	700	224
CPU (min)	11.1	120.3	1.3	< 0.1	< 0.1
Objective Function	-1.952	4.048	-1.926	3.068	3.069
Relative Gap (%)	0.14	0.07	0.00	0.00	0.00

Table 4 – Final inventories, operational balance and indicators

Inventory (volume units (v.u.))	**R0**	**R1**	**R2**	**R3**	**R4**
P1	45 406	45 406	44 556	44 556	44 556
P2	20 614	20 614	20 613	20 613	18 113
P3	4 004	12 004	12 104	12 104	12 104
P4	26 434	18 434	18 489	18 489	18 489
P5	10 101	10 101	9 735	7 335	7 335
P6	11 780	11 780	10 919	10 919	10 919
Total Inventory	118 339	118 339	116 416	114 016	111 516
Total (Inputs-Outputs)	+ 7291	+ 7291	+ 5368	+ 2968	+ 468
Medium Flowrate (v.u./h)	500	500	507.8	504.4	502.5
Pipeline Usage (%)	98.4	98.4	96.9	96.9	96.6

The results obtained for the scenarios simulation show that it is possible to transport more than global outputs for clients, translated in positive operational balances. However, with the accumulation of changes, pipeline usage decreases and medium flowrate rises above the minimum, so as to achieve a positive balance.

Figure 2 represents inventories profiles for all products throughout all scenarios. The decrease in a lot size on product P2 can be seen at the end of the time horizon. The inclusion of a lot of product P3 instead of P4 is easily identified in both profiles. Adjustments on product P5 due to capacity reduction are also evident. In general, profiles have minor adjustments, which implies that the penalizations in the OF are adequate so as diminish the scheduling nervousness.

5. Conclusions and Future Work

The MILP model developed translates a real world scenario and produces feasible pipeline schedules and inventory management plans for medium term time horizons. It was also adapted to address a rescheduling procedure that captures the most common changes in the initial plan and is capable to manage several situations during one revision. Future work will focus further on the model performance as well as on the detailed model of the tanks farm.

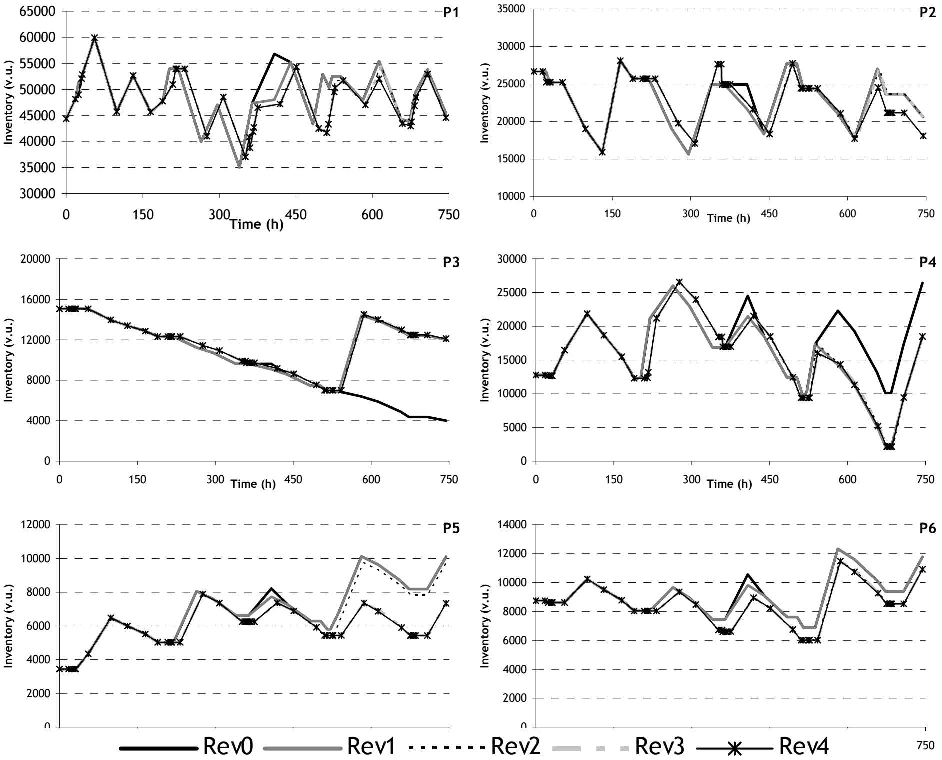

Figure 2 – Inventory profiles by product and scenario

Acknowledgements

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