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A MILP (Mixed Integer Linear Programming) decomposition solution to the scheduling of heavy oil derivatives in a real-world pipeline

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ABSTRACT

This paper presents a novel approach to aid the operational decision-making of scheduling activities in a real-world pipeline, transporting heavy oil derivatives, which are products of less aggregate value, such as fuel oils, e.g. marine fuel. These products present special characteristics that influence their transport as the impossibility of being transferred at room temperature, due to their viscosity, or the use of shared tanks for different products. Thus, during the transport of such products, the entire pipeline network (and the tanks) must be maintained heated during all the pumping process. Such characteristics imply that a specific model oriented to this type of problem must be developed. The approach proposed in this work develops a decomposition procedure that uses a sequence of mathematic programming models and heuristics to solve the problem in hand. The proposed approach is tested using a real-world scenario, composed of a pipeline tree system.

1. Introduction

The use of pipelines to transport petroleum and its derivatives is a commonly used solution within the oil supply chain. Despite the high cost of initial investment, pipelines are the most economical way to transport large volumes of products at great distances when compared to other modes such as railroads, ships or roads. Several pipeline configurations exist in the entire petroleum industry supply chain: from a single source (usually a harbour) to a single destination (a refinery), from a single source (the refinery) to several destinations (consumption and distribution centres), from multiple sources to multiple destinations, in which case the system is commonly named a multi-pipeline system (Cruz, Andrés, Herrán, Besada, & Fernández, 2003). Solutions of planning and scheduling to all these configurations have been recently proposed, in which authors emphasize the complexities that characterize the tackling of all constraints and details. However, these works propose solutions only to simplified versions of the general problem. Rejowski and Pinto (2004), Magatão, Arruda, and Neves Jr. (2004), and Zyngier and Kelly (2009) used discrete Mixed Integer Linear Programming (MILP) formulations, dividing the planning horizon into equal and fixed time intervals. This decision lead to a situation where obtained solutions are only useful if the discretization period is very small, and thus the computational time to find the optimal solution, even for small planning horizons (75–120 h), is high. Cafaro and Cerdá (2004) proposed a rolling horizon technique to this kind of problem, enabling larger time periods. Relvas, Barbosa-Póvoa, and Matos (2009) proposed a MILP model that addresses the inventory management at the final destination, but only for a multiproduct pipeline with a single origin and only one destination area. Proposals that approached more realistic versions of the problem, with several origins and destinations over a complex pipeline network, have been recently presented (Cafaro & Cerdá, 2009), applying both structural and temporal decomposition techniques to achieve a solution for the planning and scheduling problems in reasonable computational times (Neves Jr. et al., 2007; Boschetto et al., 2010).

In this paper, we follow this later tendency and a structural decomposition solution is proposed, using MILP models and heuristic approaches to solve the complex problem of heavy oil derivatives transportation. The presented approach is applied to a less common situation, in which several refineries must send their production to a single receiving area, in this case a harbour, for exportation. The approach is a development of the work first proposed by Neves Jr. et al. (2007), and further developed by Boschetto et al. (2010). However, the solution herein developed

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Nomenclature

Indices/sets

D set of days, where $d \in D$
I set of pumping parts, where $i \in I$
J set of receiving parts, where $j \in J$
L set of pipelines, where $l \in L$
N set of network nodes, where n, n', m, $m' \in N$
P set of products, where $p \in P$
$PULMAO$ sparse set containing the tuple (p,n), which is used to model surge tank operations for product p in area n
R set of routes, where r, $r' \in R$
T set of tanks, where $t \in T$

Parameters

α_l maximum desired utilization of pipeline l during the planning horizon (%)
β maximum aggregate stock (%)
cap_t maximum capacity of tank t (v.u.)
$CP_{n,p}$ maximum aggregate capacity of product p in area n (v.u.)
$CPagr_n$ maximum aggregate capacity in area n (v.u.)
$Cps_{i,j}$ pumping start volume constant for residence part related to pumping part i and receiving part j
$Cpf_{i,j}$ pumping finish volume constant for residence part related to pumping part i and receiving part j
$Crs_{i,j}$ receiving start volume constant for residence part related to pumping part i and receiving part j
$Crf_{i,j}$ receiving finish volume constant for residence part related to pumping part i and receiving part j
$demLiq_{n,p}$ consumption (demand) of product p in area n during the planning horizon (v.u.)
$disp_{n,p}$ available quantity of product p in area n (v.u.) during H
$flt_{n,p}$ required quantity of product p in area n (v.u.) during H
H planning horizon (h)
$LI^{\min}_{n,p}$ minimum aggregate storage of product p in area n (v.u.)
$LI^{\max}_{n,p}$ maximum aggregate storage of product p in area n (v.u.)
M large value
$MaxChTq$ maximum number of tank swaps
$NumOfDays$ number of days
$NumChIn_t$ number of tank swap t
$PerMin$ minimum period of days before tank swap
$PerTq_{t,p}$ period of days that tank t stores product p
$Q^{\min}_{n,n',p}$ minimum quantity to be sent of product p (v.u.)
$TresMax_{i,j}$ maximum residence time allowed for the residence part associated with pumping part i and receiving part j
vaz^{med}_r medium flow rate of route r (v.u./h)
$Vol_{n,p,d}$ volumes of products in area n in day d (v.u.)
vr_r sum of volumes of pipelines in route r (v.u.)
$util_l$ total utilization of pipeline l (h)

Continuous model variables

$CapAgr_{n,p,d}$ aggregate capacity in area n of product p in day d (v.u.)
$invent_{n,p}$ storage level of product p in area n (v.u.)
$NumChIn_t$ number of tank swap t
$PerTqPr_{t,p}$ period that a tank t is allocated to a product p
$Q_{n,n',p,r}$ amount of product p to be sent from the origin area n to the destination area n' by route r (v.u.)
$Qin_{n,p}$ amount of product p to be received in area n from all pipelines (v.u.)
$Qout_{n,p}$ amount of product p to be sent from the origin area n to all pipelines (v.u.)
$Qdegr_{n,px,p}$ quantity of degraded product px to p in area n (v.u.)
$rCapAgre_{n,p,d}$ quantity violated with respect to aggregate capacity of product p in area n in day d (v.u.)
$rNumChIn_t$ violation of swaps number of a tank t
$rPerTq_{t,p}$ violation of minimum period that a tank t is allocated to a product p
$vari_l$ additional utilization rate of pipeline l in relation to α_l (%)
$resultDeg_{n,p}$ degradation of product p in area n (v.u.)
$violResul_{n,p}$ amount of allocated and demanded product p in area n (v.u.)
Tps_i pumping start time for pumping part i
Tpf_i pumping finish time for pumping part i
Trs_j receiving start time for receiving part j
Trf_j receiving finish time for receiving part j
$VCP^{zero}_{n,p}$ quantity violated with respect to initial storage of product p in area n (v.u.)
$VCP_{n,p}$ quantity violated with respect to capacity of product p in area n (v.u.)
$VCPagr_n$ quantity violated with respect to aggregate capacity in area n (v.u.)
$VLI^{\min}_{n,p}$ quantity violated with respect to minimum storage of product p in area n (v.u.)
$VLI^{\max}_{n,p}$ quantity violated with respect to maximum storage of product p in area n (v.u.)
$VLIagr^{\max}_n$ quantity violated with respect to maximum aggregate storage in area n (v.u.)

Binary MILP model variables

$b_{t,p}$ 1, if the tank t stores product p
$bi_{t,p,d}$ 1, if the tank t stores product p in day d
$bin_{n,n',p,r}$ 1, if the product p is sent from area n to area n' by route r
$bina_{t,p,d}$ 1, if occurs a tank swap t of product p in day d

incorporates some real-world constraints that make it more applicable to real operational scheduling, such as restrictions on tank availability and heating constraints – restrictions present when heavy oil products are transported, cases not commonly treated in the published literature.

This paper is organized as follows. Section 2 provides the problem description including the problem constraints and a block diagram of the proposed hierarchical decomposition. In Section 3 the proposed solution is detailed, comprising the optimization and heuristic models. In Section 4 some results are presented, and finally in Section 5 the conclusions are drawn.

2. Problem description

The considered transport network is schematically presented in Fig. 1, which represents a real-world scenario. The multi-pipeline connects the refineries (nodes N1, N4, N5 and N7), to the harbour (node N8), passing through some intermediate areas (nodes N2, N3 and N6). These intermediate areas have heaters and heated tanks, and are used for temporary storage and re-heating of the products. All the pipelines are continuously heated, and three kinds