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An exact mathematical formulation for the optimal log transportation

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ABSTRACT

In this work, a Mixed-Integer Linear Programming (MILP) model for daily routing of trucks in forest industry is presented. The aim is to generate truck routes at minimum cost, while logs supply is guaranteed. Models usually found in the literature assume that the trips that must be made are known in advance or are generated in a previous stage. Unlike those approaches, in this work the configuration of each trip is generated along with the routing decisions. An exact formulation is developed; neither decomposition algorithm nor heuristics are used. The proposed model is evaluated on several cases, showing in all of them that the proposed approach efficiently solves the addressed problem in a short computational time.

1. Introduction

In forest industry, log transportation represents one of the major impacts on the overall costs. Then, reducing these costs represents a significant saving for companies in the sector. Forest companies have to take several decisions related to the distribution of logs from the harvest areas to the different industries that require them. Therefore, making transportation operations more efficient through an adequate planning represents a task of major interest.

Transportation planning ranges from strategic to operational decisions. At strategic level, decisions are mainly related to road investments, facilities locations and fleet management (Carlsson and Rönnqvist, 2005; Forsberg et al., 2005; Olsson, 2005; Olsson and Lohmander, 2005). At tactical level, decisions are associated to product allocation (Carlgren et al., 2006; Carlsson et al., 2014; Troncoso and Garrido, 2005), while at operational level vehicle routing and scheduling are typical decisions.

Vehicle routing in log transportation is different from traditional Vehicle Routing Problem (VRP) found in the literature. Extensive state-of-the-art works on VRP can be found in Toth and Vigo (2014) and Laporte (2009). Moreover, the log transportation problem is classified as a variation of the Pick-up and Delivery Problem (PDP). Parragh et al. (2008a, 2008b) present detailed definitions and approaches of general PDPs. A number of attributes that distinguish PDP in log transportation from a more general PDP is presented by Audy et al. (2012), where a review of the planning methods regarding the VRP in this industry is also presented.

Borges et al. (2014) define the PDP in log transportation as a set of vehicle routes that must be generated in order to satisfy a set of demand points according to a given objective and subject to a set of constraints. A route usually starts and ends at the vehicle home base and must satisfy different time constraints such as working hours availability of the vehicle (e.g. to disallow working at night), length of driver work shift, time windows at supply/demand points, etc. Also, the supply and demand sites can be visited more than once (logs availability usually exceeds one truckload as well as facility requirements).

To carry out the transportation, a fleet of vehicles is available, which may consist of the same or different vehicle types, each with an unique set of transportation-relevant characteristics (e.g. capacity, types of raw material allowed to haul, fuel consumption, set of sites not allowed or impossible to visit, etc.). The vehicles are spread throughout a set of sites or based in only one location. Therefore, the log transportation problem involves many complex decisions, which includes large number of vehicles, supply and demand nodes, different types of raw material, several starting routing points, and legal and political aspects, among others, making the resolution process very complex. Thus, developing a tool capable of treating and solving this problem efficiently and in a short computational time, is a practical and relevant issue for the industry.

Due to the complexity of this type of problems and the difficulty for obtaining optimal solution in reasonable computing time, many heuristic based approaches were proposed in the literature, as it is described in the following paragraphs.

Palmgren et al. (2003) solve a daily problem through a hierarchical solution approach, which first generates feasible routes with a heuristic algorithm. After solving the LP relaxation of that problem, an integer

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Nomenclature

Sets

C	set of available trucks c
C_p	set of trucks c that belongs to the regional base p
F	set of harvest areas f
I	set of plants i
I_m	set of plants i that requires raw material m
M	types of raw material m
P	regional bases p for trucks
V	set of possible trips v to be made by trucks

Indices

c	trucks, $c = c_1, c_2, \ldots, c_{max}$
f	harvest areas, $f = f_1, f_2, \ldots, f_{max}$
i	plants, $i = i_1, i_2, \ldots, i_{max}$
m	raw material types, $m = m_1, m_2, \ldots, m_{max}$
p	regional bases, $p = p_1, p_2, \ldots, p_{max}$
v	trips, $v = v_1, v_2, \ldots, v_{max}$

Parameters

$CL_{f,i}$	cost (in \$ per traveled kilometer) between harvest area f and plant i
$CUa_{f,i}$	cost (in \$ per traveled kilometer) between harvest area f and plant i
$CUb_{p,f}$	cost (in \$ per traveled kilometer) between regional base p and harvest area f (without load)
$CUc_{p,i}$	cost (in \$ per traveled kilometer) between regional base p and plant i (without load)
$Ctruck_c$	fixed cost (in \$ per truck used) associated with each truck c
$DEM_{i,m}$	demand of raw material m required by plant i, in full-truckloads
$DFI_{f,i}$	distance (in kilometers) between harvest area f and plant i
$DPF_{p,f}$	distance (in kilometers) between regional base p and harvest area f
$DPI_{p,i}$	distance (in kilometers) between regional base p and plant i
$MaxT$	route time limit
$OF_{f,m}$	availability of raw material m at harvest area f, in full-truckloads
$VLT_{f,i}$	average speed (in kilometers per hour) for the loaded trip that links harvest area f and plant i
$VUTa_{p,f}$	average speed (in kilometers per hour) for the unloaded trip that links regional base p and harvest area f
$VUTb_{f,i}$	average speed (in kilometers per hour) for the unloaded trip that links harvest area f and plant i
$VUTc_{p,i}$	average speed (in kilometers per hour) for the unloaded trip that links regional base p and plant i

Binary variables

$x^D_{c,\ p,\ f,\ v}$	takes value 1 if truck c begins the routing in its associated regional base p to visit the first harvest area f, 0 otherwise
$x^L_{c,\ f,\ i,\ v}$	takes value 1 if truck c makes a loaded trip v from harvest area f to plant i, 0 otherwise
$x^R_{c,\ i,\ p,\ v}$	takes value 1 if truck c makes a return trip v from the last visited plant i to its associated regional base p, 0 otherwise
$x^U_{c,\ i,\ f,\ v}$	takes value 1 if truck c makes an unloaded trip v from plant i to harvest area f to realize a new loaded trip, 0 otherwise
y_c	takes value 1 if the truck c is used, 0 otherwise

Continuous variables

$TCOST$	total transportation costs
$TIME_c$	total working time (in hours) of truck c

solution is obtained by a branch and price method. In a similar fashion, in Palmgren et al. (2004) the same problem is solved by applying a k-shortest path algorithm in the branch and price method. Rey et al. (2009) propose a Column Generation (CG) method for solving a similar formulation to the one proposed by Palmgren et al. (2003), but in this case the linear relaxation of the model is solved via dynamic column generation. A CG method to tackle a multi-period configuration is proposed by Rix et al. (2011). Later, Rix et al. (2014) generalize the previous model to take into account loader synchronization.

In El Hachemi et al. (2011), the authors present a decomposition approach based on Constraint Programming (CP) and Integer Programming (IP). In their approach, transportation tasks are pre-defined, so the objective is to minimize the total cost of non-productivity activities such as waiting time of trucks and forest loaders and distances traveled by empty trucks.

A hierarchical approach to solve the weekly problem is proposed in El Hachemi et al. (2013). In the first phase a MILP model is used to determine the destinations of full truckloads from forest areas to wood mills. In the second phase, two different methods to route and schedule the daily transportation of logs are used: a Constraint-Based Local Search approach (CBLS), and a hybrid approach involving a CP based model and a CBLS model. The same problem is solved in El Hachemi et al. (2014) through a similar approach for the first stage, and in a second stage a flow-based model with a specialized branching strategy is used to routing and scheduling trucks at minimum cost.

Gronalt and Hirsch (2007) propose a Tabu Search (TS) method to generate daily log truck route schedules for pre-defined transportation requests. The objective is to minimize the overall duration of empty truck movements considering weight constraints on the road network, multi-depots and time windows. A Simulated Annealing (SA) algorithm considering capacity and time windows constraints is developed in Haridass et al. (2014). In Flisberg et al. (2009), the authors also propose a TS approach for the operational routing problem to decide the daily routes of logging trucks in forestry. In the first phase, transportation nodes are created using a heuristic or a mixed integer programming model (a way to decompose the problem into a standard VRP with time windows). In the second phase, VRP with time windows is solved via TS.

A recent description of the current status and challenges in forest planning is provided by Rönnqvist et al. (2015). The authors state that even if there are many approaches and methods developed for the forest routing problem, there is no exact formulation proposed in the literature and used in practice for industrial instances. Also, Audy et al. (2011) highlight that there is no article, at that moment, that jointly considers those decisions (allocation, routing and scheduling).

In order to overcome this drawback, in this work a MILP model that simultaneously generates routes, assigns trucks to routes, and sequences vehicle trips is presented. Neither decomposition techniques nor heuristic algorithms are used but an exact formulation. Decisions that are generally considered in different stages, that is, product allocation and truck routing decisions, are integrated. Approaches found in the literature assume that trips are known in advance (or are generated in a previous stage). Unlike these approaches, in this work the configuration of each trip is jointly generated with the routing decisions.

The focus of this article is on operational planning decisions, specifically in how to determine the set of routes to be performed by a fleet