Journal of Forest Economics 24 (2016) 72–81

Contents lists available at ScienceDirect

Journal of Forest Economics

journal homepage: www.elsevier.com/locate/jfe

Aggregating forest harvesting activities in forest plantations through Integer Linear Programming and Goal Programming

A.L.D. Augustynczik[a,*], J.E. Arce[b], A.C.L. Silva[c]

[a] Federal University of Paraná—MSc, Caspar-Schrenk-Weg 21, 79117 Freiburg im Breisgau, Germany
[b] Federal University of Paraná—Prof. Dr. Department of Forest Sciences, Av. Prof. Lothário Meissner, 900, Campus III Jardim Botânico/UFPR-Bloco B3, Gabinete 3 Jardim Botânico 80210170, Curitiba, PR, Brazil
[c] Federal University of Paraná—Prof. Dr. Department of Mathematics, ACF Centro Politécnico Jardim das Américas 81531980, Curitiba, PR, Brazil

ARTICLE INFO

Article history:
Received 20 April 2015
Accepted 1 June 2016

Keywords:
Clustering forest harvesting
Goal programming
Forest planning

ABSTRACT

The inclusion of criteria related to the spatial patterns resulting from forest harvesting activities is an important component of forest planning. Harvesting operations are more efficient when the harvesting areas are clustered. Therewith, it is possible to reduce the displacement of machinery and costs related to construction and maintenance of the road network. In this context, the objective of this study was to evaluate different strategies for aggregating harvesting stands in a forest plantation. We applied two Goal Programming approaches aiming at aggregating harvesting stands and an Integer Linear Programming model for including road investments into strategic forest planning.

Introduction

Spatial relations regarding the distribution of harvesting activities are important issues to consider in the forest planning. The resulting pattern of the distribution of harvesting activities plays a key role in operational aspects of forest management (Li et al., 2010). Through this information, it is possible to allocate efficiently machinery and resources involved in harvesting operations, reducing costs and guaranteeing the competitiveness of the forest enterprise in the market.

The allocation of harvesting activities affects not only the economic return coming from the forest management, but ecological processes as well (Barrett et al., 1998; Goycoolea et al., 2005). According to Gustafson and Crow (1994), limiting clear-cut sizes and dispersing harvesting areas might lead to a loss of interior forest habitat and increase on negative edge effects, e.g. alteration on microclimate and favoring generalist species (Young and Mitchell, 1994). In addition, the efficiency of harvesting operations improves significantly when stands are clustered (Smaltschinski et al., 2012). With the blocking of stands, less displacement on the field is needed, minimizing the number of non-working hours and capital costs related to forest machinery. The investment required for the road network also reduces, once the number of stands that use the same accesses for transporting the production will increase (Mathey et al., 2008).

In this sense, there are two main motivations for including harvest clustering requirements into forest planning: (1) Benefiting biodiversity, maintaining more interior forest habitat and reducing edge effects and (2) Increasing the efficiency of harvesting operations (Öhman and Eriksson, 2010). Given the importance of this subject, it is natural to consider including

* Corresponding author.
E-mail addresses: andreylessa@gmail.com (A.L.D. Augustynczik), jarce@ufpr.br (J.E. Arce), arinei.carlos@gmail.com (A.C.L. Silva).

http://dx.doi.org/10.1016/j.jfe.2016.06.002
1104-6899/

connectivity requirements in forest planning models. However, operational planning problems typically involve a considerable number of conditions and constraints, becoming difficult to solve (Murray and Church, 1995). The inclusion of spatial considerations in these models increases substantially its complexity, once it is necessary to include information about the stands and their neighbors (Öhman, 2001). Additionally, this type of problem requires the inclusion of integer variables, resulting in longer processing times to achieve the solution (Bettinger and Zhu, 2006; McNaughton and Ryan, 2008).

Some approaches were proposed in the literature with the objective of clustering forest harvesting activities. Öhman and Eriksson (2010) introduced a model to promote aggregation of stands minimizing the perimeter of the harvesting area. Öhman and Lämås (2003) presented a multi-objective model that promotes the aggregation of stands through the inclusion of a non-linear variable (effective volume) in the objective function. Gustafson (1998) introduced a model based on a dynamic zoning of the forest. In this model, the forest is divided into subsets of stands and harvesting is allowed only in one subset for each period. Carlson and Kurz (2007) applied a similar approach, dividing the forest area in aggregation units, in order to concentrate the harvesting activities in specific areas. Konoshima et al. (2011) used a model to aggregate the harvesting of forest strips, aiming to mitigate wind damage risk. Smaltschinski et al. (2012) proposed a method based on limiting the total distance between stands to be harvested inside clusters, in order to minimize harvesting costs.

Despite the relevance of the theme, the aggregation of harvesting areas has not received much attention in the literature, compared to maximum harvest area scheduling problems, which aim to limit the size of clear-cut areas. Although, models for clustering forest harvesting were proposed, the quantification of operational benefits, i.e. reduction on road construction and maintenance costs due to stand clustering, has not been explicitly integrated in such models. In this context, the objectives of this study were: (1) To propose and compare different approaches to promote the aggregation of harvesting areas over the planning horizon (2) To quantify the reduction on road investments when stands are aggregated and (3) To propose a model for including road investments into spatial forest planning.

We applied two approaches for aggregating harvesting areas: (1) A model aiming at minimizing the residual degree of harvesting stands over the planning horizon and (2) A model for maximizing the number of adjacencies between harvesting stands. We solved an Integer Linear Programming problem for both approaches, defining a threshold for the NPV loss. The results, in terms of number of adjacencies and residual degree were applied subsequently as performance thresholds to a Goal Programming model. For the quantification of road network costs we defined the length of road network scheduled for renovation in a given year, based on the stands scheduled for harvesting, applying a minimum cost flow model. For integrating road investments into long term forest planning, we solved the minimum road cost model without aggregation requirements, defining the optimum harvesting schedule for increasing operational efficiency.

Material and methods

Aggregating harvesting activities aiming at benefitting wildlife

ILP Models

Achieving the complete connectivity of harvesting areas is a difficult combinatorial optimization task. These problems usually involve complex and exponential number of constraints, requiring long processing times and frequent infeasibilities. In this sense, applying alternative models, which promote, but do not guarantee the connectivity of harvesting areas, are useful to achieve suitable responses in acceptable processing times. One alternative to formulate such models is the maximization of the adjacency between stands over time.

Considering a graph G = (E, V) defined by a set of vertices (V) and a set of edges (E), connecting adjacent vertices. The degree of a vertex d(v), represents the number of edges incident to it. Considering k(v) as the potential number of edges incident to the vertex v, the residual degree of v is given by the difference between k(v) and d(v) (Brown et al., 2005).

Applying these concepts to a forest planning problem, we can consider each stand of the area as a vertex and the adjacencies between stands as the edges of a graph. The potential number of edges incident to a stand is the number of stands adjacent to it. The degree of this stand is the actual number of neighbors selected for harvesting in the same year as this stand. If we minimize the difference between the number of neighbors and the number of neighbors harvested in the same year, i.e. the residual degree of the stands, it is possible to promote the connectivity of harvesting activities. To formulate this problem, we substitute the original objective function of an ILP model of NPV maximization by the residual degree minimization:

$$MinZ = \sum_{i=1}^{N}\sum_{j=1}^{P} D_{ij} \quad (1)$$

s.t.

$$\sum_{k \in \delta(i)} x_{kj} \geq n_i x_{ij} - D_{ij} \; \forall i, \forall j \quad (2)$$