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An optimization model to solve skidding problem in steep slope terrain

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ABSTRACT

Designing an optimal off-road transportation network to allow access of logging systems to harvest sites is an important task in operational harvest planning. To address this issue, we have designed two variants of the capacitated network flow problem based on an integer programming (IP) approach with two sets of inter-dependent decisions. One set of decisions involves finding a feasible *k*-tree path network through segment linkages (routing flow) at a minimum variable cost, while another attends to the schedule of an even wood flow to the landing location(s) (transporting flow), within the scope of operational planning horizon. The mathematical models are then linked to a heuristic algorithm to identify the landing locations at the parcel level. The models were applied to a 680 ha area in the highlands of the Hyrcanian forests, in the north of Iran. The new formulation solved the problems using binary decision variables to represent transport of saw-logs from timber entry nodes to destination(s) by use of a ground-based machine skidder system. Then, the model uses continuous decision variables to represent transport of wood fuel to the same destination(s) by use of an animal skidding system. The results showed that the skidding costs and the length of the designed skid-trails were different based on the skidding systems and the types of products desired. Even though the models could generate an optimal

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solution, both of them could not address the real isolated timber node problem, where there is no accessible pathway for a skidding operation. As a promising point, the second model (splittable, animal systems) could partially solve the temporarily isolated timber nodes problem, where the timber nodes were not accessible by ground-based machine skidder systems.

Introduction

Decisions regarding the spatial arrangement of route locations, access roads for ground-based harvesting systems, and feasible design of landing locations over the steep terrain regardless of harvest decisions are considered complex problems; they can influence economic returns and environmental impacts (Søvde et al., 2013; Parrott and Contreras, 2014). Identifying the optimal transportation network to access a harvest site is part of an operational forest planning process, and represents a key element in determining wood supply chain costs (Murray and Snyder, 2000; Rönnqvist, 2003; Karlsson et al., 2004; Shahi and Pulkki, 2013). Thus the development of sophisticated planning approaches is necessary to overcome difficulties in modeling and solving this type of combinatorial problem, especially in areas of steep terrain where a plan must satisfy several conflicting issues such as environmental limitations, road capability standards, and the need to maximize economic objectives. The skid-trail network and associated primary transportation system can account for 25–50% of the total delivery timber costs (McDonald et al., 2001a; Bredström et al., 2010). Therefore, even small increases in transportation efficiency can amount to significant savings in operational and environmental costs, particular in steep terrain, thus further underscoring the importance of the problem under study. Traditionally, the time-consuming spatial design of a skidding network and landing locations has been manually determined by engineers and transport planners with a set of tools such as topographic maps and spatial databases containing stand characteristics (Liu and Sessions, 1993; Newnham, 1995; Baskent and Keles, 2005). Economic concerns were usually the primary issue when using the manual method. The manual process is too slow, laborious and expensive for fairly large-scale areas, and solutions to these problems come without a guarantee of an optimal solution. In addition, it is nearly impossible to efficiently compare and analyze several potential plans developed using manually techniques.

The difficulty with optimally solving these types of problems within the scope of operational planning horizon (days, months) has led researchers to propose several computerized models and solution methods for (sub) optimally solving skid-trail network problems (Weintraub et al., 1995; Epstein et al., 1999; Chung and Sessions, 2001; Jayaraman and Ross, 2003; Eriksson, 2006; Chung et al., 2008). Dean (1997) used a heuristic called branch evaluation technique to design a preliminary method to access the potential harvesting sites, and concluded that the method failed to reproduce the skid-trail network developed by engineers in cases when two or more alternatives with nearly identical costs exist. Murray (1998) and later Picard et al. (2006) referred to this problem as a multiple target access problem (MTAP) for locating optimal routes between timber entry nodes and destinations. Chung and Sessions (2001) also developed a meta-heuristic algorithm to locate main access roads and allow access to multiple stands. They concluded that their algorithm was appropriate only for small-scale planning endeavors. Contreras and Chung (2007) used Dijkstra's shortest path algorithm to address the optimal landing location and skid-trail network from stump locations to candidate landings, minimizing total skidding costs. Shirasawa and Hasegawa (2013) also solved the MTAP in terms of the Steiner tree problem with 14 different heuristic algorithms. Søvde et al. (2013) presented two optimization models based on greedy and meta-heuristic approaches to solve the skid-trail network problem; they concluded that the objective value of the solution found by the meta-heuristic approach was 5.6% better those found by the greedy approach. Najafi and Richards (2013) presented the MIP model based on a network design formulation, and they incorporated trucking and skidding decisions into the objective.