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Research paper

Modeling work plan logistics for centralized biomass recovery operations in mountainous terrain

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ABSTRACT

Industrial timberland managers and biomass contractors are faced with a variety of challenges when implementing biomass recovery operations in mountainous terrain. Utilizing a centralized grinding supply chain with modified dump trucks to pre-haul loose slash and a decoupled chip truck transportation system has been found to maximize the utilization rate of machines and productivity of forest residue recovery operations in northern California. This study used a spatial analysis approach to identify the optimal locations for centralized grinding and trailer landings based on the spatial distribution of biomass, existing road networks, and terrain characteristics. The network analyst in ArcGIS was used to model the supply chain logistics from the harvest unit to the energy facility. The resulting models provide explicit details on developing an operational work plan that can be used to cost-effectively implement large-scale centralized biomass recovery operations on industrial timberlands. Optimization of system logistics resulted in low costs of collection and transportation as well as improved access to recoverable forest residues. This was done by identifying the locations of landings, amount and distribution of recoverable forest residues, and modeling an efficient forest residue freight supply chain. Through the use of spatial and network analysis, operational mangers will now be able to develop a comprehensive work plan that provides a framework for centralized biomass recovery operations.

1. Introduction

Harvesting merchantable sawlogs generates significant amounts of forest residues (or referred to as biomass in this paper) that can be used as alternative energy source to fossil fuels. Forest residues refer to low value biomass material such as treetops, limbs, chunks, small-diameter and non-merchantable trees, that are the byproduct of timber harvesting or thinning operations [1]. Forest residues left from conventional timber harvesting and mechanical fuel reduction thinning have created an opportunity to generate renewable energy while achieving forest management objectives [2]. However, the removal of these low value forest byproducts from remote locations can often present both financial and operational challenges.

The high costs of collection and transportation when coupled with limited access to remote locations has proven to be a significant barrier to biomass utilization [1]. Northern Humboldt County (41.06, −124.03) is characterized by steep mountainous terrain that geographically isolates forest residues and restricts road access resulting in increased transportation distance and cost. At 100 km or less (round trip), transportation costs of "bone dry" residues alone can exceed 30 $ t^{-1}. Transportation costs combined with a current market price of 50 $ t^{-1} for comminuted forest residues in northern California creates significant financial challenges for biomass contractors to overcome [3]; therefore, it is crucial to carefully plan and implement forest residue (biomass) recovery operations due to the narrow profit margins between the delivered and market prices.

Currently, the logistics strategies of removing and utilizing biomass for bioenergy have proven successful in Humboldt County, California. Biomass recovery operations in timber harvested stands could potentially yield a cost savings of 140 $ ha^{-1} to 1120 $ ha^{-1} compared to pile and burn site preparation. Biomass removal eliminates the need for herbicide treatments as fire adapted species are less likely to sprout [4].

Defining and modeling biomass supply chain logistics is critical

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for land managers who are interested in developing a comprehensive work plan which efficiently collects, processes, and transports forest residues for bioenergy production. Numerous geospatial models have been developed to estimate forest residue availability, optimal plant locations, plant sizing, and demand at national and regional scales on a strategic planning level [4–9]. Though many large-scale models exist, the links between forest residue availability, timber harvesting, and biomass supply chain logistics on an operational level are frequently disregarded [9]. Modeling operational management requires explicit knowledge of biomass supply chains as an ordered sequence of events beginning from timber harvest and ultimately to energy conversion [10]. With this regard, network analysis (ArcGIS 10.2) is a powerful tool that has been used to dynamically model realistic road network conditions such as speed, connectivity, optimal routes, shortest path, and drive-time [4,11]. As centralized biomass recovery operations (CBROs) continue to gain popularity, it is essential that operational managers are aware of the necessary strategies and tools available to plan and implement successful operations.

The objective of this study was to develop a methodology which helps create detailed work plan logistics for CBROs by defining the strategies utilized in northern Humboldt County, California, using spatial analysis. Inventory levels, materials and equipment management, transportation, and end-use location were all included within the supply chain logistics boundaries. The outcome of this study can help contractors and landowners to plan daily operations for one or more seasons of biomass recovery. This is achieved by modeling site specific information which includes forest residue recoverability, centralized comminution and trailer landing locations, transportation efficiency, and overall operational feasibility. The model was created through spatial and network analysis of the entire CBRO supply chain as well as by directly linking timber harvesting operations to biomass recovery.

2. Methodology

2.1. Study area and timber operations that generated forest residues

A spatial analysis approach was used to model centralized grinding operations on even-aged managed industrial timberland in northern Humboldt County, California. The study site covered 22,891 ha, of which 898 ha were available for biomass recovery harvests. The timber harvesting system adopted for each harvesting unit was dependent on slope conditions, which ranged from 0 to 66°. Slopes less than 19° permitted ground-based shovel logging and slopes exceeding 19° necessitated a cable yarding system. During cable yarding, merchantable timber was assumed to be uphill yarded and processed at the landing; the subsequent forest residues were also piled at the landing. In shovel yarded units, forest residues were concentrated near the road side, which traverses throughout the setting [12]. Harvesting method was predominantly whole-tree harvesting for both cable and shovel logged units. Forest residues were left in the field to dry for one to three years after timber harvesting occurred; furthermore, residues at this time were assumed to have an average moisture content of 35%.

Road access within the study area was limited by steep slope conditions, road surface, and road type. Road surfaces were primarily gravel and dirt, and were designated as “mainline”, “secondary”, and “seasonal” road type. Mainline roads were two-lane, graveled, and had low grades. Secondary roads were single-lane and either graveled or dirt surfaces and were navigable by trucks with off-road capabilities. Seasonal roads were the least accessible, had dirt surfaces, steep grades, and were accessible only by modified dump truck and the tracked loader.

The following terms were used to describe the CBRO that was modeled in this study:

- Biomass/forest residues – Byproducts generated during a timber harvesting operation, which predominantly consists of limbs, chunks, and non-merchantable trees within the harvest unit that can be collected and comminuted
- Collection point/log landing – The point in which all the recoverable forest residues within the harvest unit are located
- Centralized landing – The site in which forest residues are dropped off by a modified dump truck (MDT), comminuted by a grinder, and loaded into an all-wheel drive (AWD) chip truck
- Trailer landing – The site in which AWD chip trucks drops off the full chip trailer and picks up an empty chip trailer. The full chip trailers are later picked up by the highway chip trucks, thus decoupling the CBRO supply chain

2.2. Centralized biomass recovery operation supply chain

The CBRO supply chain began with a loader (Linkbelt 3400) in the unit, which collected, piled and loaded forest residues into a MDT (Volvo A35C), which was modified with skidder tires for greater traction as well as an extended rear gate and side walls for an increased load capacity of 5.4 t^{-1} (Fig. 1). The second phase, referred to as pre-hauling, involved MDT hauling the forest residues to a centralized landing where they were dumped and loaded into the grinder (Peterson Pacific 5710c) for comminution. Comminuted forest residues were then belt-fed directly into an AWD chip truck with a 92 m^3 capacity trailer. The AWD chip truck traveled on forest roads to a trailer landing that was accessible by highway capable chip trucks. Here the loaded trailers were dropped off and empty ones were picked up for the return trip. This phase was referred to as primary hauling for this study. Secondary transportation refers to when the loaded trailers left at trailer landings are finally picked up by highway chip trucks and transported to energy facilities.

2.3. Development of model parameters

The methodology for developing a work plan for CBRO logistics began with identifying the timber harvesting systems and forest residue collection points (log landings) through spatial analysis and calculation of forest residues recoverable per hectare. Network Analysis (ArcGIS 10.2) was then used to identify suitable centralized and trailer landings based on proximity to recoverable biomass, transportation distance, and MDT availability. The geospatial data used for the various components in the study, such as harvest units, roads, trailer landings, centralized landings, etc, were primarily vector-based. Slope and elevation were estimated from raster-based 10 m digital elevation models (DEMs), which were subsequently used to determine the harvesting system adopted for each unit. All model parameters for both planning and operating stages were based on the expertise of a biomass contractor and chief forester with over 30 years of experience in CBROs.

2.4. Biomass recoverability and spatial distribution

The methodology for determining the spatial distribution of forest residues was based on the distinction between harvesting systems to accurately model pre-haul routes and forest residue locations (Fig. 2). The harvesting system for a unit was determined by two sets of tasks. DEMs were converted to a slope vector layer, which was then clipped to the unit's boundary. In the next task, a function of slope hectares to total unit hectares was developed for