A solution procedure for forest harvest residue collection for bioenergy

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Abstract

Forest residues are a source of biomass that can be used for the production of liquid fuels and electricity. However, residues are not often available at roadside and collection operations are required before comminution and transportation. In this study we present a mixed-integer programming solution procedure to optimize the collection of residues from different residue pile locations inside the unit to previously identified potential landings along the road. On each potential landing it is assumed that processing machinery, such as a portable grinder, can be placed at the site and chip-vans are able to reach the location. We represent the problem as a network in which each residue pile represents a source node and each roadside landing is a potential intermediate destination connected to a final node representing a bioenergy conversion facility. The model is focused on units harvested using ground-based methods. The collection model systems include: forwarder-excavator loader-grinder and forwarder mounted mobile chipper with set-out trailers. Results indicated that forwarder-mounted chipper cost is highly sensitive to increases in distance from the residue pile location to the landing and represent an expensive option compared to the forwarder-grinder system. The use of one excavator, two forwarders and one grinder appears to be the most cost effective option when residue is located 300 ft or more from the roadside landing. For shorter distances the material can be collected and moved using one excavator loader followed by road-side processing with a grinder.

Keywords: Optimization, economics, forest residue, collection, bioenergy.

1. Introduction

In recent years there has been increasing interest in the use of forest residues for bioenergy production. Some experiences in the Pacific Northwest, USA, include the establishment of power plants based on forest and mill residues (Seneca, 2011, Freres, 2012) which have increased the interest in finding cost-effective collection processing and transportation systems. Additionally, a regional institutional effort has been implemented to study the feasibility of jet fuel production from forest residues (NARA, 2011).

With ground-based logging operations, forest harvest residues are left dispersed in piles at different locations within a forest unit. To reduce transportation cost, facilitate the handling and reduce heterogeneity of the material, residues are processed by grinders or chippers (Hakkila, 1989). Grinders must be placed at roadside locations to process the material, thus, residue must be collected and transported from different locations within the harvest unit to roadside landings that must also allow access of chip vans. The collection can be performed by forwarders

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combined with excavators to facilitate the piling and loading process. Alternatively, forwarder-mounted mobile chippers can be used to reach and process the material in-situ. Mobile chippers have the ability to reach different piles within the unit, process and travel back to the landing to dump the processed residue (Bruks, 2011).

In this paper we propose a solution procedure to determine the most cost effective collection and processing system on forest units harvested with ground-based equipment given different residue pile locations, potential roadside landings and terrain conditions. This paper contributes to efficient the forest biomass collection system design by presenting a network approach. In the following section we formulated the problem and described the solution procedure; in the third section we illustrated the application of model to a harvest unit and describe the relevant results and extensions.

2. Problem formulation and solution procedure

Forest residues exist in piles at different locations within a forest unit. At each pile, residue can be either processed in situ using a forwarder-mounted mobile chipper or transported to a roadside landing for further processing by grinder. Each landing has to provide good access to chip vans to transport the grindings/chips to a bioenergy conversion facility (Figure 1). The problem is formulated as a directed network $Z = \{\mathrm{N}, \mathrm{L}\}$, where N represents a set of nodes that are an abstract representation of the residue pile locations, potential processing options and potential landings. The set of links represent the cost of moving/processing the material for each alternative from each source residue pile to the bioenergy conversion facility.

The problem consists of two types of decision variables discrete and continuous. A discrete variable represented as $w_i \in \{0,1\}$ is a binary variable modeling whether the residue is processed in situ using a forwarder mounted mobile chipper ($w_i = 1$) or collected to a roadside landing using a forwarder ($w_i = 0$). This variable also indicates if a landing at node i must be established or not. Roadside landings will be needed for placing the grinder and loading trucks and also to place set-out trailers to receive the chips if the forwarder-mounted mobile chipper system is used. The continuous variable x_{ij} represents the flow of biomass tonnage on the arc a_{ij}.

The cycle stages for the forwarder-grinder system include: traveling unloaded to the pile location; loading; traveling loaded back to the landing; unloading; grinding; and transporting using chip vans. Cycle stages for the mobile chipper include: traveling to the pile location; chipping; traveling back loaded to the landing; dumping into set-out trailers; and transporting using chip vans. In both systems it was assumed that residue was previously piled within the harvest unit using an excavator loader.

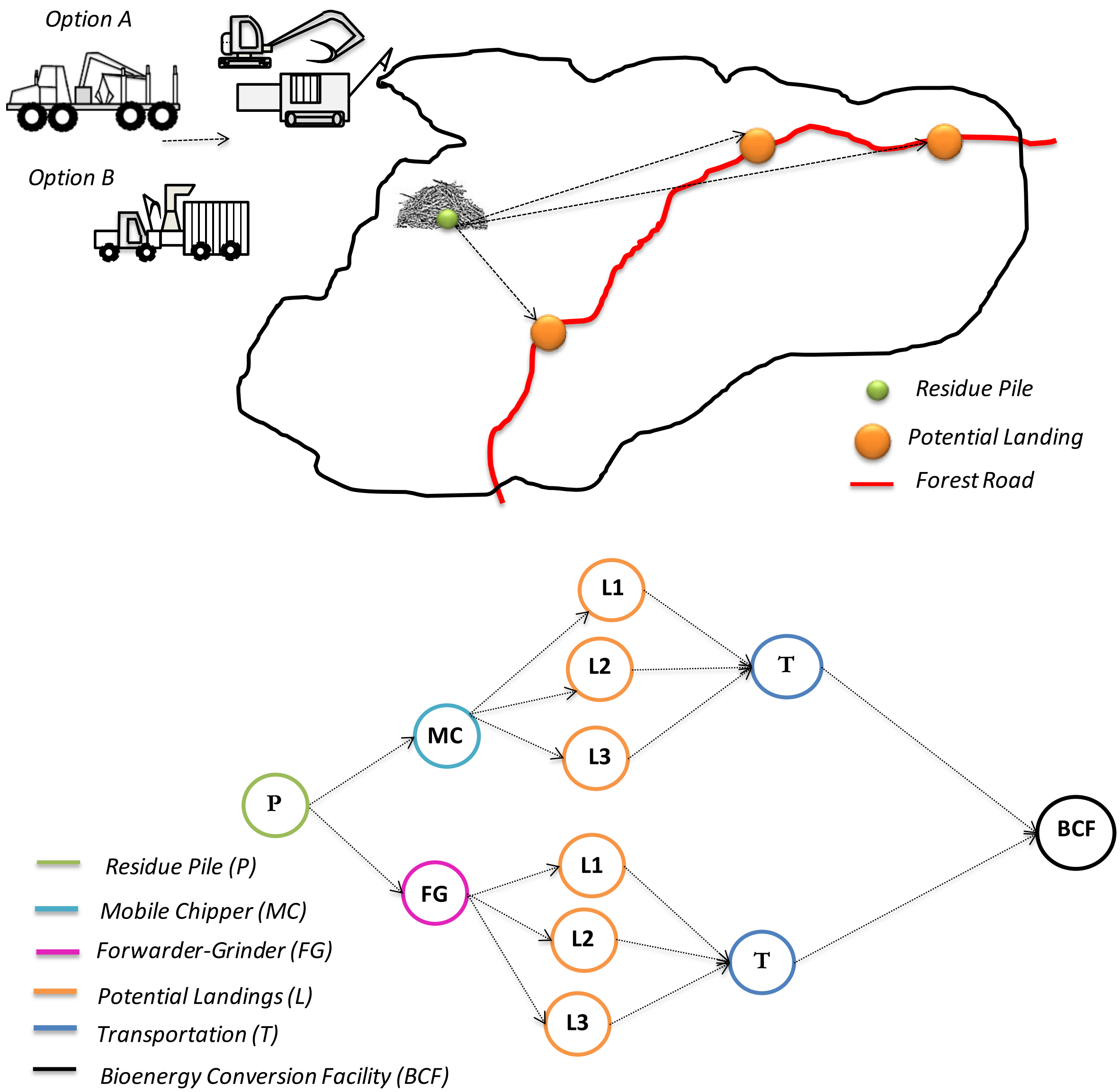

Figure 1. Problem description and formulation as a network.

3. Application of results

The model was applied in a unit located 9.5 miles east of Corvallis, Oregon, USA, (44°32'53"N, 123°25'17"W). The unit was harvested in April, 2013, using ground-based equipment. The terrain averaged 18 percent slope. Eleven residue piles distributed at different locations within a 34.8 acres unit were identified and their coordinates recorded. Residue piles consisted of a mixture of branches, and tops from an approximately 50 year-old Douglas-fir (*Pseudotsuga menziesii)* stand. Three potential landing locations were identified based on road access and available space for placing trailers and machinery (Figure 2). We assumed that residues were transported to the nearest cogeneration facility located 38.9 miles south on Eugene, Oregon, USA. Average residue moisture content was 50% green basis.

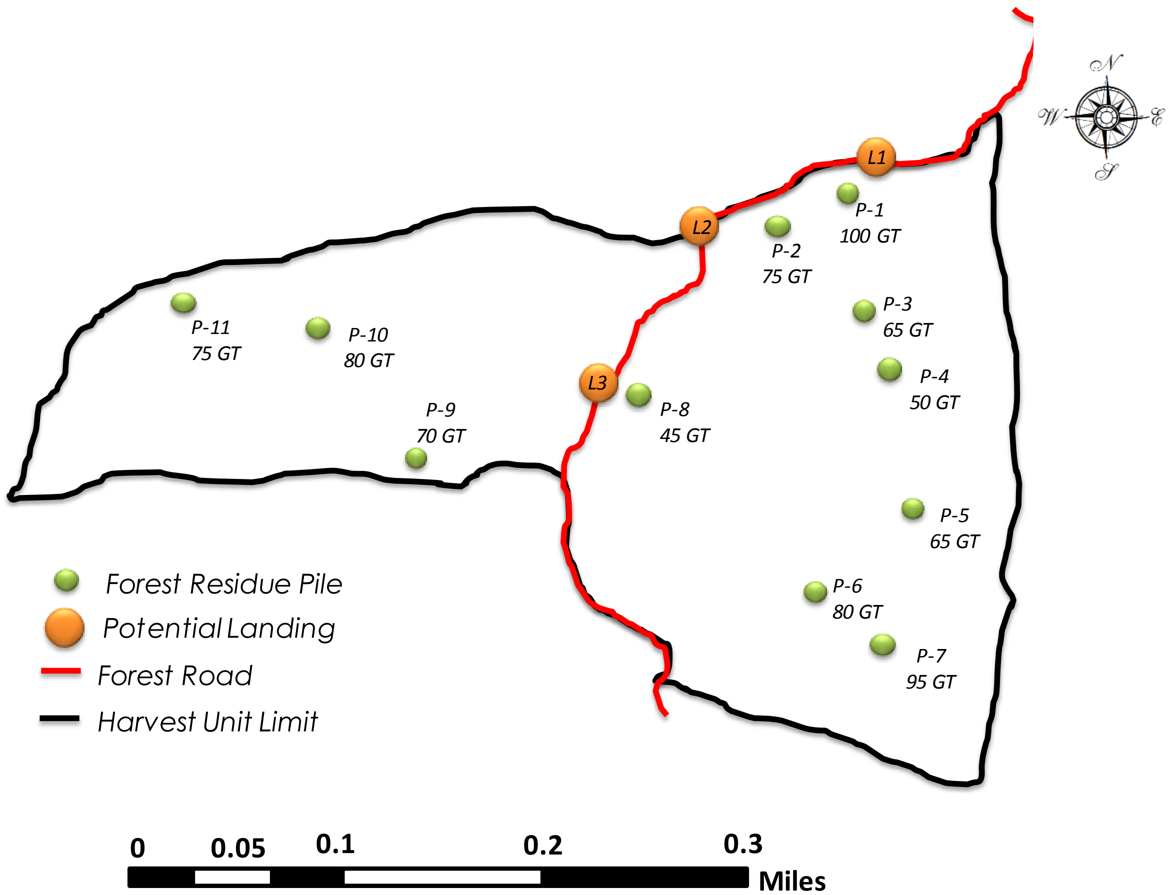

Figure 2. Map of the unit describing the pile location, volume in green tons (GT), and three potential roadside landings.

The distance from each pile to each potential landing was calculated using ArcGIS software (ESRI, 2012). A digital elevation model (10 m pixel resolution) combined with the Oregon vegetation/land use raster was used to estimate potential traffic constraints in the harvest unit. We used both datasets for identifying the least steep route that avoided water-courses and riparian zones from each pile to each landing.

After calculating the distance from each pile to each potential landing, we proceeded to estimate the cost for each of the systems in each route. Hourly costs were adapted from Brinker et al. (2002) and combined with personal communication with machine manufacture companies and contractors. Truck transportation costs were calculated based on the power required to overcome rolling and air resistance while traveling loaded and unloaded. We estimated the average time elements of each of the systems based on different time studies performed in western Oregon and then we performed different simulations to estimate the cost of the systems for each pile-landing combination (Table 1).

Table 1. Time elements and hourly cost of mobile chipper and forwarder-grinder systems.

System 1	Load green tons/cycle	Time chipping /grinding/loading (h)	Average speed MPH	Time un-loading (h)	Hourly cost $/h
Mobile Chipper (450 Hp)	4.93	0.17	1.47	0.02	366
Chip van double trailer 32-32 ft	30.00	-	45-highway/ 10-gravel	0.83	126
System 2					
Excavator Loader (150 hp)	-	0.09	-	-	103
Forwarder (173 hp)	8.39	0.09	2.41	0.12	134
Horizontal Grinder (750 hp)	24.00	0.48	-	-	398
Chip van 45 ft	24.00	-	45-highway/ 10-gravel	0.50	118

Results indicate that the most cost effective system for all the piles is the use of the forwarder-grinder system, using two forwarders to maintain grinder productivity. Although this systems adds two machines to the process (the forwarder and the excavator loader to feed the grinder), the higher productivity appears to compensate the higher cost of the additional equipment. Productivity of the mobile chipper ranged from 23 green tons per productive hour (distance of 63 ft from pile to landing) to 6.8 green tons per productive hour (distance of 2,032 ft from pile to landing). The mobile chipper productivity was highly affected by the distance from each pile location to the potential roadside landing (Figure 3).

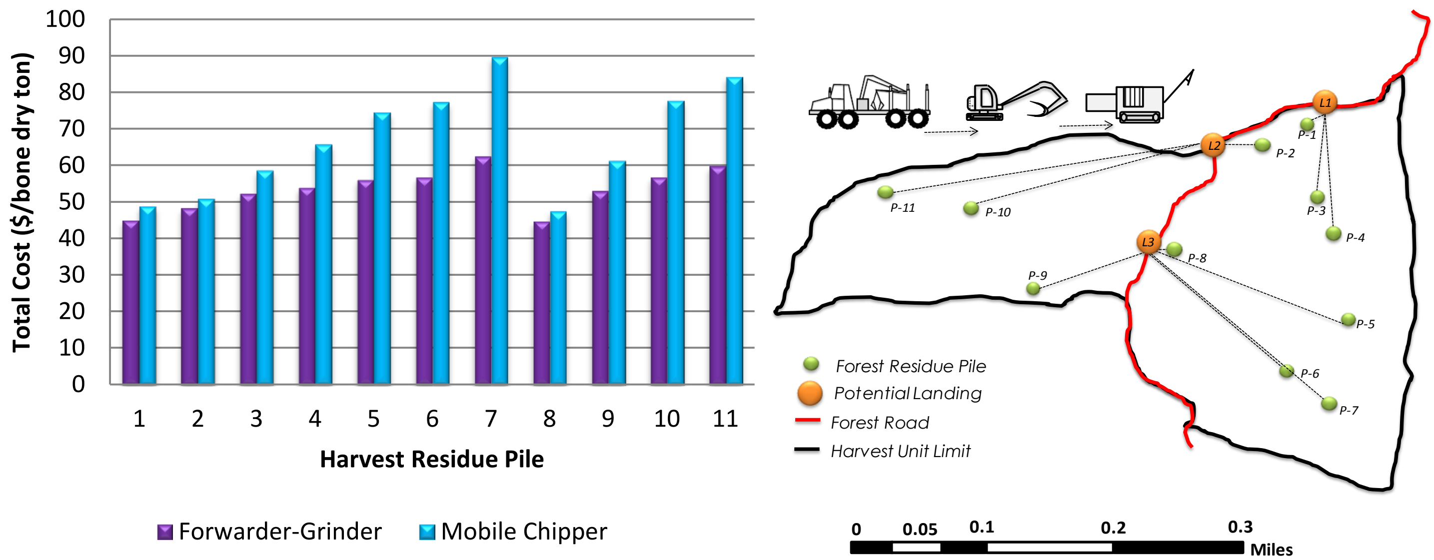

Figure 3. Total cost and landings selected per pile for the analyzed harvest unit.

4. Conclusions

At first, the mobile chipper system appeared to be a cost effective option given that the use of forwarder and grinder are avoided. However we found that chipper productivity is highly affected by distance. Since the capacity of the chipper bin is limited to approximately 5 tons, the cost per trip increases rapidly when distance from the pile to the landing increases. Potentially, the preprocessing of the residue piles to preselect cleaner and larger pieces before chipping may help to improve chipping times but adding one more process to the cycle will increase costs. We still consider that the mobile chipper could provide some advantages over the forwarder-grinder system if the characteristics of the final product are taken into account by the markets. Chips tend to be homogeneous in particle size compared to grinders, however in actual markets we could not identify any price premium paid for field chips versus grindings. The forwarder-grinder system is feasible for residue piles located at a distance greater than 300 ft. The use of two forwarders is required or the grinder would be underutilized. This can be a constraint for small contractors who may not have the financial capability to invest in two forwarders. The use of the excavator loader to load the forwarder is the key to increasing the payload and decreasing loading times. Future research will combine simulation to improve the cost estimation of the systems and will develop additional alternative systems than can be tested.

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