XI. Concurrent Session 4B – Spatial Analysis in Forest Operations

Assessing Spatial Distribution and Availability of Forest Biomass by Harvesting System in the Pacific Northwest, USA

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To support the biomass supply model for a regional forest residue to aviation fuel project (NARA), we evaluated the spatial distribution of biomass by harvesting system and estimated distance to road. The NARA project is a USDA funded project with the objective of evaluating a supply chain from forest biomass to aviation fuel production. The base resource data are FIA plots. To improve our understanding of the topography, likely harvest system, and distribution of forest residues we developed a GIS-based model. We present a methodology based on the processing of vector and raster data that can be used at the regional level. Regional data (digital elevation models, road networks, ownership, landcover) was collected from the primary federal and state agencies. Digital elevation models were processed to estimate the amount of forested land that could be suitable for either ground-based or cable equipment. We then combined the harvest system overlay with the road system. In cable terrain, residues were assumed to be at roadside. For ground-based systems we assumed part of the residues is generated at roadside landings and part was generated in the field at different distances from the road. The results from the analysis will be used to characterize the biomass collection and comminution costs for biomass generated in the vicinity of each FIA plot. Validation of the GIS processing is done by comparing model results with the harvest unit layers on the state of Oregon forests.

Key-words: Biomass, spatial analysis, harvesting systems.

1. Background | Introduction

The Northwest Advanced Renewable Alliance's mission is to provide economically viable and socially acceptable regional solutions to support the creation of forest residuals to bio-jet industry in the Pacific Northwest (NARA 2015). A critical element of this mission is to properly identify and evaluate the forest residuals supply chain which includes the extraction, transportation and comminution of forest residuals along with processing and other auxiliary activities required to sustainably produce bio-jet fuel at scale. A main objective in the NARA project is to accurately estimate supply chain costs by developing economic modeling protocols in an effort to better utilize existing resources and site locations for future infrastructure placement.

Supply Chain Cost Structure

Feedstock costs (Phase #1) include collection, transportation and grinding of residuals prior to production facility processing. These costs account for roughly 33% of the total supply chain operational expenses (OPEX) while Phase #2 costs (pretreatment, processing at the mill and distribution costs) account for nearly 67% (Wolcott 2013). This paper will limit discussion to the operational feedstock supply chain cost structure within the NARA economic modeling framework. In particular, we will highlight the collection cost structure, its current estimation methodology and importance while suggesting ways to refine model inputs and incorporate spatial data. Figure 1 illustrates the typical regional residual supply chain structure.

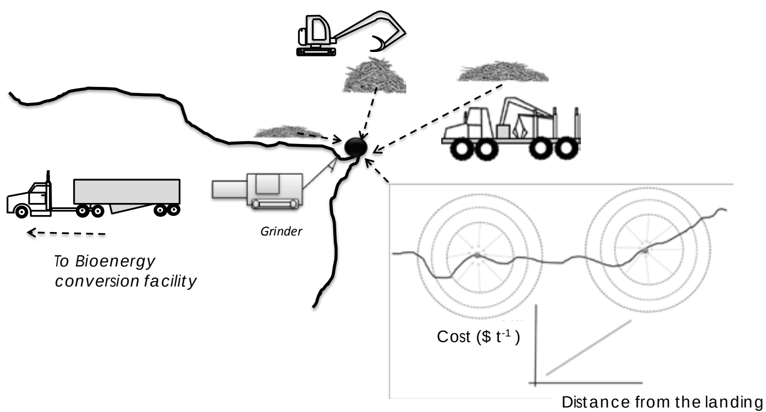

Figure 1. Typical forest harvest residue collection system in western Oregon and Washington (Zamora and Sessions 2014).

Collection System Utilization

Two main harvesting systems (ground-based and cable-based) are used for most logging operations in Pacific Northwest forests. Ground-based systems (typically shovel logging) are generally utilized when slopes are less than around 30% for safe productive work (Conway 1976, MacDonald 1999). Cable-based systems are generally employed on steeper slopes. As a general principle, ground-based systems are more cost effective solution if conditions are suitable (Lousier 1990, Jarmer et al. 1992).

When utilizing cable systems, the residuals are primarily located at a landing site adjacent to roadside and thus readily accessible. Alternatively, ground-based logging systems such as shovel logging typically disperse a larger volume of residuals in the field with a smaller fraction located at roadside. Usually residues are not moved directly to roadside, but are moved to discrete landings along the roads for comminution. This is important as the distance to roadside is the primary collection cost driver and subsequent barrier to sustainable utilization. Studies suggest that residuals which are piled and within 150 feet of roadside cost roughly $5-10/ BDT compared to $20-30/ BDT for material that is further from roadside (Zamora and Sessions 2015). Subsequently, collection costs can vary by a factor of six, ultimately varying overall feedstock costs by up to 25%; accounting for nearly 10% of the entire operational supply chain cost structure.

For ground-based harvesting systems two distance bands are the most logical for evaluation, the area within 300 feet of a road, and the area outside of 300 feet. If residues are to be transported less than 300 feet, the least expensive method is by excavator. For harvest units with residue collection distances greater than 300 feet adding one or more forwarders loaded by an excavator can be more economical if the equipment is available.

2. Problem Description

The NARA biomass supply model relies on the Forest Inventory and Analysis (FIA) database for the description of forest characteristics. In order to project when and where forest biomass residues will be created the NARA biomass supply model simulates commercial timber harvest to meet regional product demands using a variant of the Timber Assessment Market Model developed by Adam and Haynes (1980). The NARA biomass supply model allocates the volume of commercial timber harvest that will occur at each plot center in each time period considering timber characteristics, logging costs, and transport distances. In the NARA biomass supply model forest harvest residues are a byproduct of the timber harvest, they do not drive it. To develop the supply, the quantity of biomass and cost of delivered biomass must be calculated. Currently the NARA biomass supply model assumes all forest harvest residues at a plot point are available on truck at the same average cost. This method does not incorporate any spatial information of the site which will greatly impact residual accessibility, harvesting method and thus projected collection costs and volumes. The objective of this paper is to develop a methodology that can be used to refine the average cost of getting forest biomass to roadside.

Project Objective and Outputs

From a modeling perspective we need to answer the following key questions: What harvest method is likely to be used at a specific location? How many acres of forested land within state and private ownership classes are in close proximity to existing roads? How much and where is the area available for near term harvesting on a per FIA plot basis?

The specific goal of this project is to classify state and private forest land that is likely to be harvested within the next 25-35 years (i.e., not recently harvested) and falls into one of the following four categories: cable-based, ground-based within 150 feet of road, ground-based between 150 and 300 ft of a road, and ground-based beyond 300 ft of a road. Our contribution is to develop a methodology for incorporating spatial data to further refine the collection costs input to NARA's supply chain economic model. The information provided will be customized to meet these input requirements. We discuss how the model is applied (via point and sample dataset) in western Oregon and will be extended over the entire NARA region. We also present how the model compares to Oregon Department of Forestry (ODF) historical harvest data while exploring its limitations and overall implications to the NARA cost model.

3. Model Description

Methods

In order to solve this problem, ArcGIS 10 geospatial software and the Python programming language were utilized to manipulate and automate data processing (ESRI 2015). Key input data included: FIA point locations (USFS), Regional Road Networks (State), Digital Elevation Models (USGS DEMs), Protected Areas Data (USGS) and Global Forest Change (2000-2013) mapping data (Hansen et al. 2013a). The process was broken up into distinct phases including 1) pre-filtering the data, 2) spatial processing and discretizing, 3) road data processing and 4) land cover change analysis designed to answer the key questions related to estimating the underlying harvesting method, land type, road offset and land availability questions.

The general methodology is based on sampling a 1250ac area around the FIA point location, subdividing this acreage into 50ac subplots which were then analyzed to estimate a harvesting method and subsequent residual collection criteria related to road offset distance and area availability (Figure 2). Each subplot was then assigned an estimated harvest unit type which became the basis for the analysis.

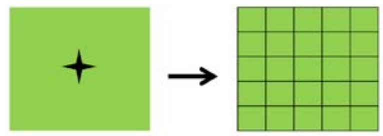

Figure 2. Conceptual model of land area discretizing (rasterizing)

Pre-Filtering Data

In this project, residuals are assumed to be solely a by-product of commercial logging operations. As such, the NARA project is primarily interested in productive sites from state and private land ownership classes rather than federal sites where production is limited. Only forested state and private FIA points were selected for analysis.

Spatial Processing

Once the FIA points were filtered, the point data was then used in conjunction with state specific DEM data to create a square buffer/ DEM raster around the point encompassing 1250 acres. The FIA DEM raster file was used as the input file for the slope function which output the percent slope at each point within the dataset. This raster file was then reclassified into two segments depending on the percent slope (<30%, >30%). This reclassified raster dataset was then split (discretized) into twenty-five 50 acre subplots. The 25 individual raster files where then reclassified again in accordance to their percentage of either likely ground-based systems (<30%) or cable-based systems (>30%) based on area majority. At this point the land is effectively reclassified in accordance with harvesting method with discrete raster and shape files for each of the 50 acre subplots.

Road Data Processing

Once the individualized 50 acre subplot data was generated, road data is imported into the system and manipulated with a similar process being utilized to separate the data into the desired 1250ac units (namely data masking). The plot level shapefiles were then buffered with a 300 ft offset to determine approximate area available adjacent to the roadway. Finally, only the ground-based system plots were then compared to the road offset shapefiles to determine approximate areas within the 300 ft buffer.

Land Cover Change Processing

In order to get a more accurate assessment of the overall land available for harvest in the near term, land that was recently harvested was removed. The Global Forest Change dataset (Forest Cover Loss Layer) was utilized as a supplemental data layer. Similar to the other processing features, this dataset was sub-sampled and matched at the subplot level and then combined with harvesting system data. This allowed us to determine land area available for future harvests within each harvest class.

4. Application and Results

Study Area

We applied and compared the model results to actual harvest units in Oregon with data provided by the Oregon Department of Forestry (ODF). This was done to modify and compare this method before extrapolation to the entire NARA region. Below, we illustrate the methodology as applied to 1) a single FIA plot and 2) a series of 39 FIA plot locations in the Astoria region of northwest Oregon for comparison. It is important to note that this methodology is to be preformed for all the plots in the entire NARA region which includes Oregon, Washington, Montana and Idaho to standardize economic model inputs.

State Forest Comparison – Single Plot Example

For illustrative purposes and to provide an example of the actual output to be delivered to NARA, the analysis was applied to a single FIA plot (Figure 3) located in northwest Oregon (45° 24’ 3.19”N, -123° 33’ 18.84”W).

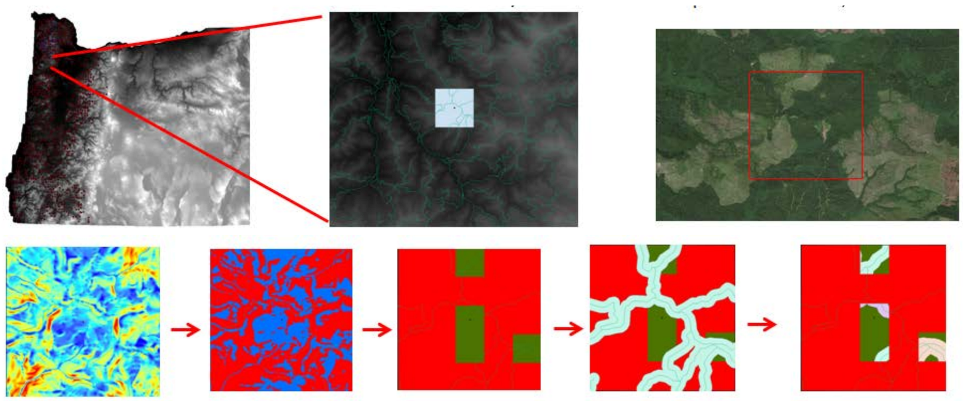

Figure 3. Example of proposed methodology: FIA plot location, point envelope, Google Earth aerial imagery, slope manipulation, reclassification and discretization, road system 300 ft offset buffer overlay.

It is important to note that on a per-plot basis the individual results will vary. ODF harvest units are predefined, irregular and tailored towards the site terrain and local logistics beforehand, while the model is a blanket interpretation of the area cut into pre-defined segments based on slope. While the results on a per-plot-basis are highly variable it is anticipated that from a system-wide view the method provides a realistic representation.

When reviewing a single plot we can also qualitatively see the efficacy of the land available and harvesting unit approximations. When viewing the land from an aerial perspective, we see a clear correlation of land available for harvest from the ground cover change layer when compared to actual aerial imagery (Figure 4). Additionally, we see that (in this case) the model harvest unit does a good job at approximating ground-based systems as the dominant area (middle of the unit, Figure 4). Overall, for this point, the model over-predicted ground-based operations by roughly 8% (Table 1). An over-prediction like this would provide a more conservative approximation of accessible residuals in the sense that a fraction of ground-based residues are not at roadside and must be collected as opposed to residues from cable-based harvesting systems at roadside. The NARA input is the percent of the private or state forested land within the 1250 acre sample that has not recently been harvested and falls into one of the following four categories: 1) cable-based, 2) ground-based within 150 ft of road, 3) ground-based between 150 and 300 ft of a road, and 4) ground-based beyond 300 ft of a road (Table 1). NARA would apply those land area percentages as part of the biomass cost estimation process.

Figure 4. Comparison of ODF harvesting systems with model projections. Google Earth Overlay, Global Forest Change Layer, ODF Harvest Unit separation, ODF Harvest Unit (Dark Green is 70% ground, light green is less than 40%, all others are cable system).

Table 1. Example Comparison of ODF vs. Model projections for a single 1250ac Plot (45° 24’ 3.19”N, -123° 33’ 18.84”W). Model NARA Input File generated based on available land area only.

		ODF Total	Model Total	NARA Input (Of Available)
System	Ground-Based Systems	8%	16.00%	
	Cable-Based Systems	92%	84.00%	
Availability	Ground-Based Available		50.99%	
	Cable-Based Available		65.87%	87.15%
	% Available Overall		63.49%	
Systems Area	Ground-Based 150 ft Offset		20.72%	2.66%
	Ground-Based 300 ft Offset		41.43%	2.66%
	Ground-Based Other		100.00%	7.53%

State Forest Comparison

The methodology was compared to 39 FIA plot locations which represented approximately 48,750 acres (Figure 5). With this data, we compared and analyzed the overall harvesting system allocation by overall area as well as review information from a per-plot-basis. We can see that, similar to the single plot example, the composite data compares favorably with the ODF data where cable-based system area was underestimated by 0.59% and ground-based systems area overestimated by 5.86% (Table 2). When reviewing the ODF harvest unit data compared to the model on a per-plot basis we see that the average overestimation towards ground-based system is roughly 6% with a standard deviation of about 25% (Figure 6).

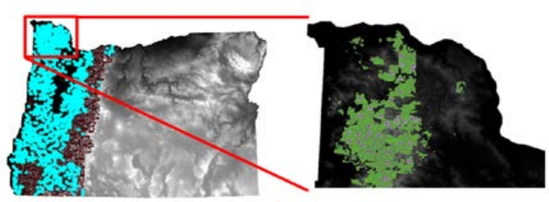

Figure 5. Oregon State Forest Validation Zone, Northwestern Oregon

Table 2. Comparison of ODF vs. Model projections for 39 points where data is available.

	ODF	MODEL	DIFFERENCE
Ground-Based Systems	25.42%	31.28%	5.86%
Cable-Based Systems	69.31%	68.72%	-0.59%
Helicopter	5.27%		

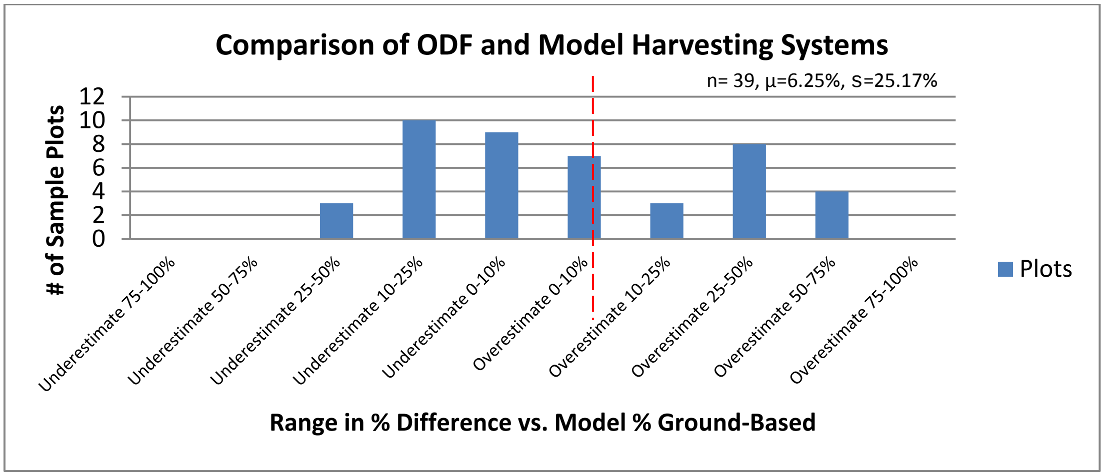

Figure 6. Comparison of ODF and modeled harvesting systems for the 39 FIA plots (1250ac area each) based on % difference of model predicted ground-based area. Data normalized to exclude helicopter and non-harvest areas.

It is likely the model over-predicts ground-based systems due to broader terrain characteristics that favor cable-based operations (i.e. raised road system along a ridge adjacent to milder slopes). Conversely, the model may under-predict due to its inability to capture situations where ground-based systems are used to harvest easily accessible timber near roads to supplement the cable operation.

5. Conclusions

This methodology provides a framework for estimating residual accessibility on a landscape scale. Overall, this method provides a simple, logical framework for estimating operating harvest system and associated landscape harvest residue accessibility and distance from roadside characteristics on a spatial scale; an improvement over the current method.

Limitations | Sensitivity

This method employs a simple discretization technique that cannot characterize all the dimensions of an actual harvest unit such as size, placement, method, road logistics or a combination of methods in a specific area. The logic in our simplified method uses assumptions of harvest unit size, harvest system selection, and harvest system homogeneity within the harvest unit. We discuss the sensitivity of these assumptions below.

FIA Unit Plot Centroid/ Layout Design

In this study, the plots were assumed to be simple squares surrounding the projected FIA plot centroid. In reality, FIA plots are not delineated in this fashion, with the point reflecting the centroid of a spherical area. Additionally, since the FIA point placements are 'fuzzed' to begin with, the actual area (and thus residual quantities) are only approximate.

FIA Unit Plot (1250ac)

For analysis purposes, we chose a 1250ac plot to be representative of the FIA area. This design was primarily chosen due to overlapping areas (with larger plots), irregular point placement and to standardize the size. In reality, an FIA plot typically represents a 6000ac area (though there are plot variants). We assume this sample to be characteristic of the broader area.

Harvest Unit Size (50ac)

We assume a 50 acre harvest unit subplot throughout the study as this correlates well with the Pacific Northwest practices, industry norms and the data obtained from our ODF sample. In our 39 plot sample we see a harvest unit average of 52 acres. However, a standard deviation of 27 acres with the overall range in excess of 100 acres illustrates the highly variable nature of the data. Additional sensitively analysis by varying harvest unit size showed best results when using a 50 acre model harvest unit size (Table 3).

Table 3. Comparison of ODF vs. Model projections for 39 points. Percent difference of ground-based systems compared to observed (normalized for no helicopter or other system utilization) when varying individual harvest unit size (25ac, 50ac, 140ac).

	25ac Model	50ac Model	140ac Model
AVG % Difference	7.41%	6.25%	7.16%
Standard Deviation	23.60%	25.17%	27.83%

Harvest Method Slope Indicator (30%)

In order to identify the harvesting system, we used a 30% cutoff to differentiate ground-based systems (<30%) and cable-based systems (>30%) based following classifications used by Conway (1976), Dykstra (1997), and MacDonald (1999). While this is the often used, there has been a trend toward using ground-based equipment on steeper slopes. Additional sensitivity analysis showed that this variable (as expected) was particularly sensitive to estimated system choice with 30% being a fairly accurate representation.

Table 4. Comparison of ODF vs. Model projections for 39 points (normalized for no helicopter or other system utilization) when varying the harvest slope indicator (20%, 30%, 40%).

	ODF Values	20% Model	30% Model	40% Model
Ground-Based Systems	25%	16%	31%	51%
Cable-Based Systems	69%	84%	69%	49%
Helicopter / Other	5%			

Harvest Unit System Cutoff (50%)

In conjunction with the slope indicator, we used a simple slope majority rule to denote likely harvesting method. While this will likely explain many logging practices employed, it will not account for combinations of harvest systems used within any given harvest unit. From the 39 ODF plots, we saw that nearly 48% of all actual harvest units used a combination of harvest systems with an average of 30% difference between ground and cable-based logging systems.

Temporary Roads

We used regional road network data. Temporary dry season spur roads, not on the regional road network data, would shorten collection distances on ground-based units. To the extent that these occur, the method here would underestimate the area close to roadside.

6. Future Work

This paper presents a simple, logical technique to estimate the spatial area that can contribute to harvest residual extraction. The model is designed to provide input percent areas to the NARA economic model in an effort to further refine the estimated collection costs portion of this model. This study shows that this technique can be employed (with clear limitations) in order to further refine this model and clarify harvest residual accessibility within the region. Future work to enhance this model could focus on three areas. First, it is thought that the largest source of error is related to harvest unit configuration. In order to improve the process, more sophisticated rules could be developed to reconfigure the harvest units to follow watershed boundaries, topographic contours and roadways. Second, additional data such as soil stability, vegetation type, riparian areas and other sensitive areas could be added to better approximate land available, systems constraints and subsequent residual locations. Third, it would be beneficial to have a greater number of comparison zones (points) in a variety of conditions and States to further refine and test key assumptions regarding slope delineation, harvest unit system cutoff and harvest unit size.

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