WEST VIRGINIA FOREST INDUSTRY TRANSPORTATION NETWORK ANALYSIS USING GIS

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Abstract.—To better understand and increase efficiency in delivery of harvested roundwood on West Virginia's roadways, a detailed network analysis using Geographic Information Systems (GIS) was conducted. Typical proximity-based analysis, which looks at straight-line distances (buffers) around given features regardless of terrain and road characteristics, provides limited knowledge of true transportation costs, i.e., travel time. This is especially evident in West Virginia's roadways, of which there are far fewer flat and straight than a proximity analysis would suggest. Furthermore, 6,343 bridges currently are associated with these roadways, many with weight restrictions that limit the effectiveness of proximity-based analysis.

To better serve the forest industry, a Timber Supply Area was established to understand how West Virginia road transportation systems correspond to the available hardwood resource. A transportation network analysis using U.S. Census road networks with associated speed limits, and current primary producing mill locations, were used to identify Sawmill Service Areas based on drive times. Sawmill service areas coupled with available private forest lands, using both grid- and vector-based analysis, provide a more comprehensive analysis of transportation costs.

INTRODUCTION

The West Virginia timber supply and sawmills that require raw logs for processing are connected by the log trucks that traverse the complex network of roads. In the Appalachian region, loggers identified trucking as one of the more limiting segments of the forest harvesting process, especially for small producers (Luppold and others 1998). A limited supply of trucks, longer haul distances, and increasing fuel costs (Mendell and others 2006) all contribute to the need for a better understanding and planning of the timber transportation networks that connect the forest resources and processing facilities.

Trucking distances play a very important role in the overall costs, productivity, and availability of trucking resources. Usually, the longer the distance a truck must travel, the higher the variable costs in labor, fuel, and required maintenance and the lower the overall productivity in volume of timber moved. By spatially identifying discrete commercial forest lands and the locations of sawmill processing facilities, we can analyze transportation networks to identify potential timber resources available within a transportation-economical range of each mill.

OBJECTIVES

The connections between timber supplies and sawmills can be investigated through network and suitability analyses using Geographic Information Systems (GIS). These analyses incorporate the more than 250,000 private forest landowners who control more than 90 percent of the State's forest land (Magill and others

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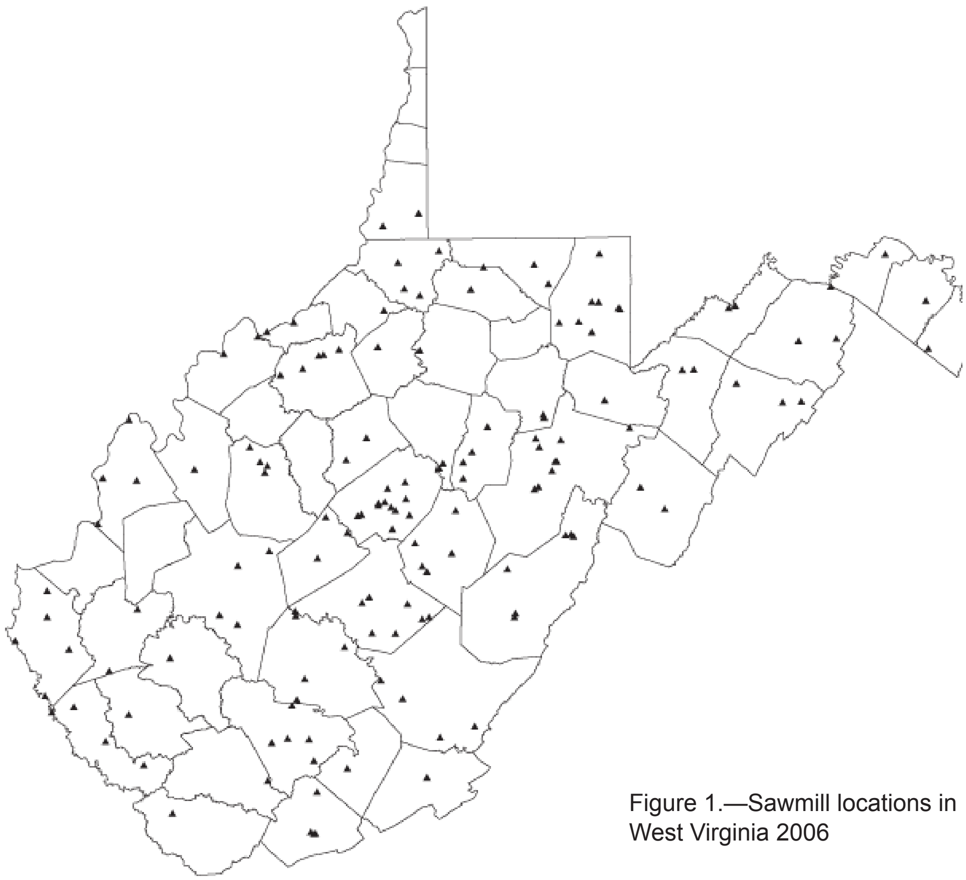

Figure 1.—Sawmill locations in West Virginia 2006

2004), and land-use suitability criteria that establish the appropriateness of the land for timber production. These Timber Supply Areas (TSAs), or areas throughout the State that are appropriate for commercial timber production are identified by distinguishing high quality private forest lands from all other land types. Sawmill Service Areas (SSA), or those areas (on any land use) that are within an economically feasible distance from West Virginia's 156 sawmills (Fig. 1), can also be identified. This analysis uses several statewide data layers associated with the hardwood forest resource and industry, including: topographic slope, threatened and endangered species habitat, U.S. Census road networks, proximity to roads, low weight bridges, private forested land, U.S. Forest Service Forest Inventory and Analysis (FIA) county data, existing forest stewardship lands, and sawmill locations. Each of these layers is combined using GIS to evaluate the transportation time of harvested timber from each identified TSA to existing sawmills.

This analysis process can provide a better understanding of the true area accessible to a sawmill based on log-truck travel times. The process also identifies timberlands that are not well served by primary processors. In fact, the TSA areas outside the reach of existing sawmills may be quality locations where new wood-product processing facilities could be located.

METHODS

To understand the transportation time involved in this study, TSAs were first established by means of a multi-layer overlay. Network analysis was then used to create SSA polygons. Finally, the SSA was overlaid on the TSA to calculate percentage overlap with each SSA. The data layers and processes used in the analysis are detailed in the following sections.

Analysis Mask

Model Builder in ArcGIS 9.2 (Environmental Systems Research Institute, Redlands, CA, 2006) was used to create an analysis mask (Fig. 2) that excludes areas outside the state boundaries and areas not considered private timberland (open water, urban areas, and National Forests, and other public lands) from the analysis.

Private Forested Lands

National Land Cover Data 2001 (Vogelmann and others 2001), developed from 30-m Landsat Thematic Mapper data from the Multi-Resolution Land Characterization Consortium, was queried for West Virginia land cover types representing forested land (Deciduous-41, Evergreen-42, and Mixed-43), and wetlands (Woody-91, Emergent Herbaceous-92).

Forest Patches

Roads, highways, and utility rights-of-way were subtracted from the private forest lands data from above in order to create a layer of forest patches. These patches were combined into operationally appropriate forest management patches of 1,000 acres (404.7 ha).

Threatened and Endangered Species

This data layer shows areas in proximity to threatened or endangered species habitat or blocks of land considered a unique or important habitat type. These blocks were derived from the West Virginia Division of Natural Resources (WVDNR) Natural Heritage Program database. All threatened and endangered species habitats from the WVDNR Natural Heritage database were selected and given a half-mile buffer, the recommended buffer distance developed by the WV Stewardship Planning Committee for the statewide stewardship program. These habitats were then converted to a 30-m grid and classified as areas not proximal to threatened or endangered species or areas in proximity using Boolean logic.

Topographic Slope

This raster data layer describes areas of West Virginia where slope is more than 5 percent and less than 40 percent. Percentage slope was derived from 30-m Digital Elevation Model raster files (U.S. Geological Survey 2006) using the ArcInfo Spatial Analyst Slope tool. The resulting grid cells were reclassified—1 for values between 5-40 percent and 0 for all remaining values.

Proximity to Roads

A road network dataset for West Virginia was extracted from ESRI's TIGER 2000-based StreetMap USA Nationwide Streets network dataset and a raster layer of all roadways was created with a 500-m buffer. This buffer approximates the maximum log skidding distances from the stump to a roadside landing. Those areas within the typical operational range for current logging systems were coded as close proximity, and those areas that exceed the 500-m distance were classified as not close proximity using Boolean logic.

Existing Stewardship Lands

Data layers from the WV Stewardship Spatial Analysis Project sponsored by the U.S. Department of Agriculture, identified approximately 630,000 acres of West Virginia forest land that is under forest stewardship. These areas are considered priority timber supply areas that are actively managed. Existing Stewardship Plan polygons were converted to a 30-m grid and classified according to whether a stewardship plan was present using Boolean logic.

FIA Data

Four datasets from the FIA program were used in this analysis. These data were as follows: volume of private growing stock on timberland by county; the volume of private sawtimber on timberland; the ratio of private growing stock removals to growth on timberland; and the ratio of private growing stock removals to growth on timberland. Mean values in each of these categories were calculated and used to classify each county as equal to or above the mean, or below the mean, using Boolean logic. This process was used to create four data layers that identify those counties with mean or above-mean volumes of growing stock on private lands, where growth of sawtimber exceeds the volume currently removed in harvesting.

THE OVERLAY MODEL

Model Builder

ArcGIS Model Builder was used for the TSA overlay model suitability analysis. This model spatially combines, by addition, the 11 data layers previously discussed. The analysis mask, which has a multiplier value of one, will force the analysis to occur only in areas with private timberland potential. Use of the mask will also ensure that all data layers overlay appropriately. Once the overlay model was implemented, the resulting TSA potential layer cell values were reclassified using the Natural Breaks classification algorithm to determine areas of low, medium, and high timber availability potential.

Sawmill Service Area Creation—Network Analyst

The road network dataset previously used had an additional data field that calculated travel time based on speed limit and road segment length. To enhance the routing accuracy of the service area polygons, a geometric data file with low-weight bridge locations (Gula 2007) identified the 584 bridge locations

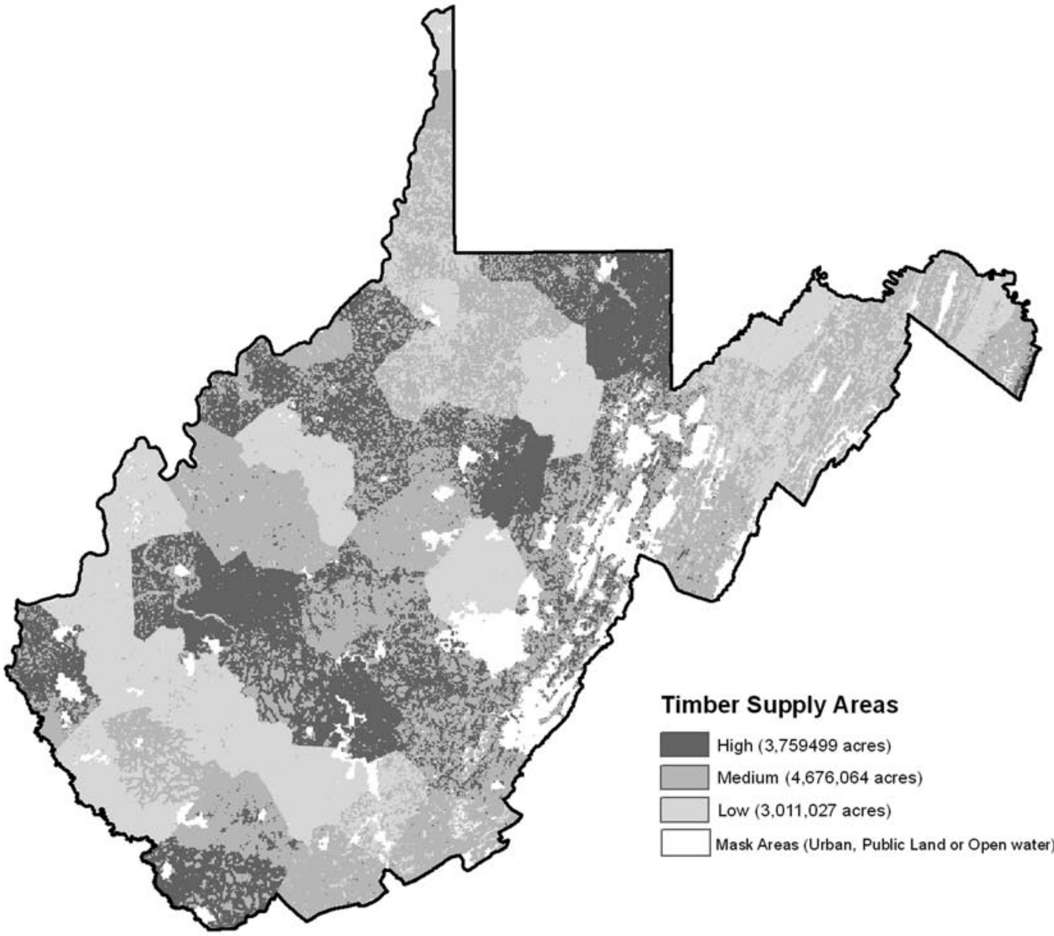

Figure 3.—Analysis layers used for the Timber Supply Areas (TSA) Boolean overlay suitability analysis.

throughout the State that have posted weight limits that do not meet requirements for typical log-truck weight classes (Spong 2007). Both bridges and sawmill location files were located on the network using a 2000-m search tolerance due to the difference in locations of the road network and feature locations. Fifteen sawmills were removed from the analysis because of ambiguous addresses.

Service area polygons were created using the ArcInfo Network Analyst extension. The service area tool was used to find actual roadway drive times in minutes based on driving towards each sawmill. To derive SSAs a 30-minute drive time was selected as an economically efficient drive time to the mill based on Barrett (2001). Resulting polygons were then loaded into the TSA overlay analysis to calculate the area in TSAs for each SSA.

RESULTS

Results from the overlay model determined that the majority of timberland area fell in the "medium" TSA category, followed by the "high" and then "low" categories (Fig. 3). The average area of the 156 SSAs was 211,907 acres with a minimum area of 60,246 acres and a maximum of 438,451 acres. On average, sawmills had 12.0 percent of their SSA in the "medium" TSA category (Table 1). This was followed by 8.6 and 8.3 percent of their area in the "high" and "medium" TSA areas, respectively. Median areas in the TSA categories were quite different. The median percent of SSA area in TSA was 1.5, 4.4, and 1.4 for the "high", "medium", and "low" categories, respectively (Table 1). Note that these values are averages of each of the 156 SSA components in the TSA categories and that the sum of these will not equal 100 percent.

Table 1.—Percentage summary and statistics of sawmill service areas classified as Timber Supply Areas (TSA) acres

156 Sawmills	Percent TSA high	Percent TSA med.	Percent TSA low
Average	8.62	12.00	8.31
Minimum	0	0	0
Maximum	65.71	69.94	68.60
Median	1.51	4.43	1.38
Std. Deviation	14.6	16.32	13.31

Approximately 1.2 million acres fell outside the 30-minute SSA for all mills analyzed in West Virginia. Most of the TSAs that did not correspond with an SSA were in the "low" category, followed by the "medium" and "high" categories (Fig. 4).

DISCUSSION

TSAs were ranked based on 11 data layers, each with some basic assumptions that would allow the model to identify areas that have more potential for greater volumes, quality, value, and accessibility. This ranking process provides the ability to identify potential TSAs using a wide variety of variables that are often too difficult to evaluate without advanced GIS analysis techniques. The data used to assess the relative quality of the TSA have been derived from many sources, which could pose to some problems. An obvious issue arises when addressing those areas that fall next to the state boundary. In these areas, road distances that are across state boundaries are not considered, potentially artificially suppressing the rank for a particular unit. Another issue comes from the scale at which the data have been collected. In data layers such as that for threatened and endangered species, the location points have been identified precisely, while FIA data have been summarized and presented at a county scale. To address this inconsistency, additional analyses that utilize more robust classification schemes, rather than the simple binary classes used in this analysis, can be used. Alternatively, a sensitivity analysis could clarify the importance (or unimportance) of the differences in data resolution.

The SSAs developed here provide additional information, as they help define haul-distance limits based on travel times. A sawmill that can procure logs from closer locations would be at an advantage over mills that are required to haul a much longer distance. As time can roughly be used as a proxy for cost (Martin 1971), the farther the haul distance to the mill, the more expensive the haul. While independent trucking contractors are often responsible for the direct cost of trucking, sawmills will incur the increased costs of long-distance hauls as the trucking costs (and all other costs to get the log to the sawmill) are applied to the value of that log. Barrett (2001) reported that one-way travel times longer than 30 minutes have a much greater percentage of the total trucking cycle time comprised of road travel. With the SSA set at a 30-minute one-way travel time, operations are more likely to be limited by loading, unloading, and delay times rather than the on the road travel time. Given that all haul distances will require loading, unloading, and some sorts of delay, those travel times more than 30 minutes have a greater impact on overall travel distances. Again travel routes are limited by both weight-restricted bridges and roads that travel outside of the state boundary. This limitation is best illustrated by the significant number of TSAs outside of SSAs in the northern panhandle area of the state (Fig. 4). In this area, sawmills located in adjacent states may have an SSA that does incorporate these West Virginia TSAs.

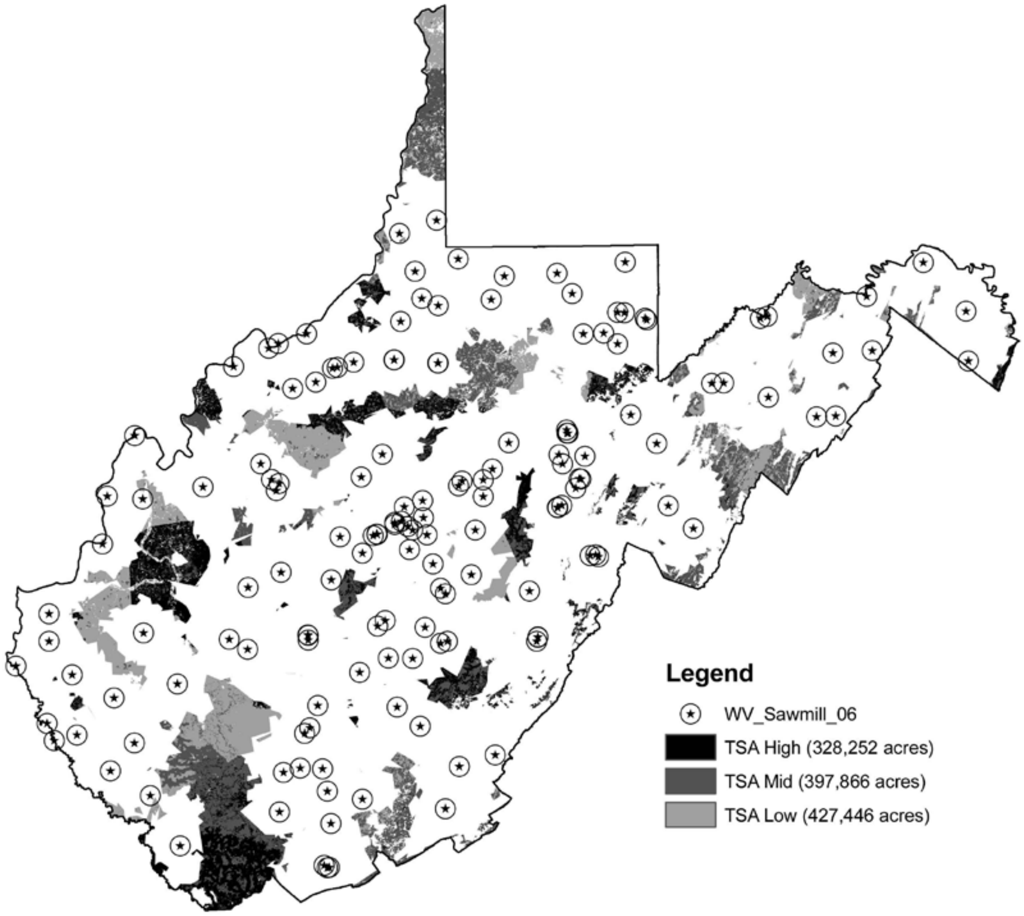

Figure 4.—Timber Supply Area (TSA) that are outside of 30-minute haul time to mills.

CONCLUSION

This analysis combines many different spatial components of the timber supply and processing activities. There are some obvious concentrations of sawmills located in the state, while there are many other areas that appear to be under-represented by sawmills. Specifically, those areas that are outside of the existing SSAs and have high TSA rankings are areas where new sawmills could be established and have relative advantages over competitors with longer haul distances and/or lower TSA rankings. While this analysis concentrated on sawmills and timber supply, the models and methods used here can provide both graphical and numerical summaries of a multitude of complex criteria to industry decisionmakers.

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