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harvesting & utilization

# Spatial Allocation of Timber Product Output Roundwood Receipts

**John P. Brown**

Data from Georgia timber product output studies were used to develop models that spatially allocate roundwood receipts data from primary wood-using mills. Mill receipts data were converted to a cumulative frequency based on a distance from the mill to a county center. Distances were calculated as either straight line or shortest road distance, and county centers were determined as geographic centers or weighted by forest mass. Logistic and Gompertz nonlinear asymptotic model forms were used to model cumulative frequency of annual receipts within a repeated measures framework. It was determined that the number of mill employees and the shortest road distance were significant factors. The Gompertz model form predicted an unbiased cumulative frequency for the 2003 data using several spatial covariance types in the repeated measures analysis. These methods demonstrate the potential to spatially allocate a mill's total receipts to its surrounding counties in the absence of county-specific recording.

**Keywords:** procurement, nonlinear mixed models, Gompertz function, logistic function, repeated measures

The timber product output (TPO) survey is one method used by the Forest Inventory and Analysis (FIA) program to assess yearly timber removals. A complete canvass of all primary wood-using mills is conducted on a state by state basis. The primary measure of interest is roundwood receipts, which is the cubic meter volume of roundwood harvested in a given (targeted) state plus roundwood imported from other states. Volumes of imported roundwood are reported back to their states of origin for their TPO reports. The state targeted in the survey then reports production as the sum of the roundwood volume harvested and processed in that state plus the volumes reported in the receipts data from other states. The data collected provide important information on the amount, county of harvest, and species composition of roundwood harvested within each state for the survey year.

TPO surveys help to satisfy requirements of the 1997 Resources Planning Act (RPA). The Forest Inventory and Analysis (FIA) units of the USDA Forest Service have standardized data collection to report removal data nationwide. Roundwood removal data are reported down to the county level for the survey year (Johnson 2001). All mills are contacted through mail or through personal contact at the mill, with follow-up telephone contact as needed (Johnson and Wells 2004, Johnson and Wells 2005). When a mill fails to respond, that translates to an underestimate for one or more counties in the region. Just a few missing mills can easily impact a substantial number of counties in the TPO study, particularly if the mill is a large sawmill, oriented-strandboard mill, or pulp mill. Some of the information sought during a TPO study may be more readily obtainable than other types. Specifically, researchers may be able to get the total receipts for a mill but not the species groups or counties of origin. This situation generates the question of how receipts might be allocated back to counties through a modeling approach.

In a Maine wood procurement study, Lones and Hoffman (1990) broke hauling distances into several distance classes and found that 90% of fibermill wood supply and 95% of sawmill wood supply came from within 200 km. Wagner et al. (2004) studied log markets in the southern tier of New York to determine factors influencing the distribution, consumption, and merchandising of hardwood logs and found that maximum procurement distances ranged from 80 to 400 km. Alderman and Luppold (2005) sampled logging operations in West Virginia and found haul distances for roundwood logs to market ranged from 30 to 150 km and varied by product class and region. A study of Finnish sawmills (Schwab et al. 2005) showed positive effects on roundwood volume from increasing mill capacity or sawmill size index using a demand equation. This same study also showed a negative effect on roundwood volume with increasing distance. Mill type (hardwood or softwood)

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This article uses metric units; the applicable conversion factors are: cubic meters ($m^3$): 1 $m^3$ = 35.3 $ft^3$; kilometers (km): 1 km = 0.6 mi.

**Table 1. Conversion factors for TPO data.***

| Class | Type | From | To | Conversion factor |
|---|---|---|---|---|
| Saw logs | Hardwood | bd ft (International 1/4 in. rule) | $m^3$ | 0.0047592 |
| | Softwood | bd ft (International 1/4 in. rule) | $m^3$ | 0.0051958 |
| Veneer logs | Hardwood | bd ft (International 1/4 in. rule) | $m^3$ | 0.004604 |
| | Softwood | bd ft (International 1/4 in. rule) | $m^3$ | 0.0048405 |
| Pulpwood | Hardwood | cords | $m^3$ | 2.12 |
| | Softwood | cords | $m^3$ | 2.06 |
| Posts | Hardwood | cords | $m^3$ | 0.018 |
| | Softwood | pieces | $m^3$ | 0.018 |
| Poles | All | pieces | $m^3$ | 0.04853 |

* From Johnson (2002) and C. Steppleton (USDA Forest Service, pers. comm., Apr. 17, 2006).

and mill size were found to affect three different procurement radii for sawmills located in the northeastern United States (Anderson and Germain 2007).

These studies illustrate that hauling distance plays a role in roundwood acquisition by mills. The specific value that the distance was measured for varied from study to study: the maximum procurement distance (Wagner et al. 2004); haul distances (Alderman and Luppold 2005); and the average distance encompassing 90% of log supply, the farthest distance to stumpage, and the farthest distance to logs (Anderson and Germain 2007). This suggests a need to explore how distance to supply is measured might fit into any modeling attempts. Rather than selecting an arbitrary fixed percentage of production, e.g., 90% or the maximum, and considering the need to allocate production to surrounding counties, this analysis develops methodology for modeling the cumulative frequency of mill roundwood receipts from counties using distance and the number of employees as factors in the models.

Brown and Oderwald (2012, p. 476) discussed that for TPO studies, "Complete canvasses can be problematic due to lack of response, limited monetary resources, lack of available personnel, and other reasons." They also mention that survey time burdens imposed on business are limited by federal regulations. Concurrent to their study goals, this study aims to also move away from canvasses, with the overall objective being to model county receipts data in relation to distance from the mills. Specific objectives are to evaluate a suitable functional form for the spatial allocation model, to assess several variations of measuring distance between counties and mills, and to determine if the resulting spatial model for the annual cumulative frequency of receipts can be inverted to produce curves representing any desired procurement radii.

## Materials and Methods

### Canvass Data

TPO data were collected for the years 2001 and 2003 from 100% canvasses of Georgia primary wood-using plants. Data were collected in 2002 for the 2001 assessment and in 2004 for the 2003 assessment by the Southern Research Station's (SRS) FIA unit. Questionnaires were mailed with additional information collected by telephone or through personal contact as needed for completion (Johnson and Wells 2004, Johnson and Wells 2005).

Data were imported to and processed in SAS, where it was necessary to convert all totals to a standard unit of measure, in this case cubic meters. Receipts totals, which were given in a variety of units, were converted into cubic meters totals using conversion factors from Johnson (2004, p. 15) (Table 1). Conversion factors not provided in that report were obtained from C. Steppleton in the SRS's FIA unit (USDA Forest Service, pers. comm., Apr. 17, 2006). These conversion factors were then used to calculate the total cubic meters removed of each species at the mill and county level.

Two summations were then performed to create receipts totals needed for later analysis. The first summation was at the mill level, with all species receipts totaled for each mill. The second summation was for each county's contribution to each mill, where all species receipts were totaled for each county.

### Geographic Data

Mill geographic locations in the state of Georgia were collected with global positioning systems (GPS) units and provided by the Southern Station FIA unit. Three mills were missing coordinates, and these were georeferenced using Google map satellite images. There were ten states for which TPO mill receipts were recorded: Alabama, Florida, Georgia, Kentucky, North Carolina, Ohio, South Carolina, Tennessee, Virginia, and West Virginia (Figure 1). Previously calculated mill receipts were added as a table to ArcMap™ and then joined to the mill layer. ArcGIS® software (Version 9.3) was used for all geographic analysis.

County polygons and road layers were obtained from the US Census Bureau's TIGER database. County shapefiles were merged into one 10-state county layer. Roads were also merged into a single layer. Forest cover data were derived from the Forest Service's Enhanced FIA Program. Forested plots from the inventories prior or up to 2001 were first selected from the FIA database (41,884 out of 70,539 plots). A plot is considered forested by FIA if it has 10% or greater stocking.

Given that all mill data are from Georgia, a customized azimuthal equidistant projection was developed centered in Georgia. The Mean Center tool in ArcToolbox™ was used to find this center and the coordinates were used as the central meridian and latitude of origin in the customized projection. Other equidistant projections commonly used for the state of interest could also minimize distance distortion.

Two variations for a county center were used to model the cumulative frequency of roundwood production for mills in the analysis. The first center generated was the geographic center (Geographic Center) for each county (Figure 2). The 10-state county polygon layer was used as the input layer to the Mean Center tool in ArcToolbox. The second county center generated was the weighted forest mass center (Forest Center) for the county. Here, FIA inventory plots were obtained from the inventory previous to the TPO collection year. These forested plots were added to ArcMap as a points layer. The forested plots within a county represent a recorded number of ha. The forest center is then calculated as the center of the plot locations weighted by the number of ha (forested) represented by the plots. This was done using the Mean Center tool and the ha

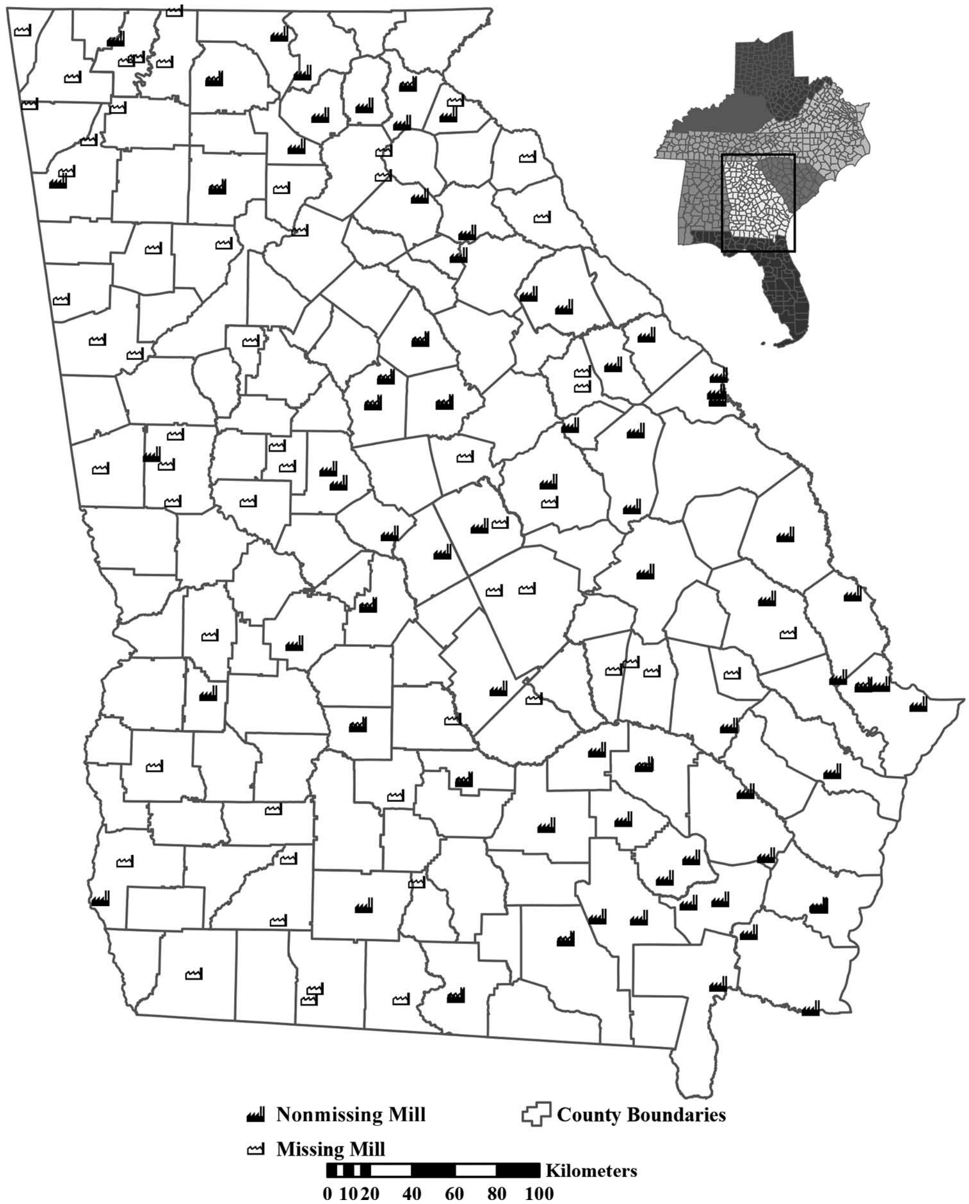


**Figure 1. Spatial distribution of Georgia primary mills. Inset shows the 10-state region contributing industrial roundwood. Map created by author.**

weights from the FIA database as the weight field. The area a sample plot represents can vary from one FIA survey to the next for various reasons due to lost plots, inaccessible plots, privacy restrictions, and other uncontrollable factors. The final result was two point layers with each point representing either the Geographic Center or the Forest Center for the county.

The next step after obtaining the center layers was to calculate the distances between the mills and the two centers. Straight line distance was the first distance computed. The Point Distance tool in ArcToolbox was invoked using first the Geographic Center layer and the mill layer. This was repeated for the Forest Center layer. This created two tables with distances from each mill to all county centers. The second type of distance generated was the shortest road route from the mill to the county center. Roads for each county were integrated into a 10-state road network built with Network Analyst™ (ArcMap) from the previously obtained TIGER roads layers (Figure 3). Mills and county centers were designated as the origin and destination layers, and the Network Analyst tool calculated the shortest road distances. Any mills or centers not directly on a road are considered to be on the closest road. Two tables of distances were again created for every mill to every geographic and forest mass center.

Four tables were thus created: straight line distance between mill and geographic center, straight line distance between mill and forest mass center, road distance between mill and geographic center, and road distance between mill and forest mass center. These distance tables were then joined to the table containing mill receipts by county, with this table also containing the employee numbers for each mill.

Last, the cumulative frequency of mill receipts was calculated for each mill. Receipts data for each mill were arranged in distance order, and the cumulative frequency was computed for each county recorded. Each mill therefore has an empirical distribution of mill receipts by county.

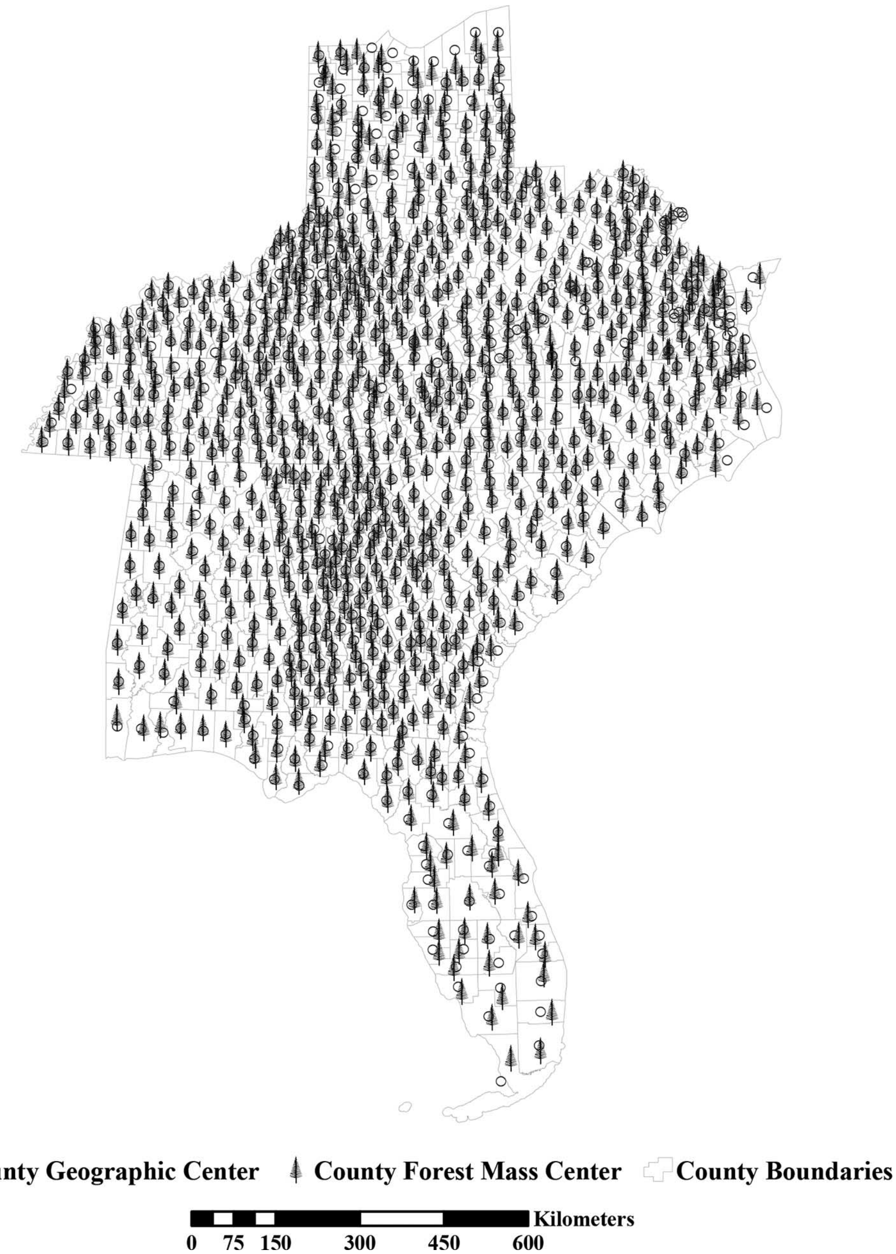


**Figure 2. Ten-state region showing County Geographic Centers and County Forest Mass Centers. Map created by author.**

### Statistical Models

The models developed related the distances from the mill to the county centers to the cumulative frequency of the receipts received by the mill for the year 2001, with 85 out of 170 mills having responded to the questionnaires. Missing and nonmissing mill data were plotted together with prior survey year's data substituted for the missing mill data to determine representativeness of the nonmissing data (Figure 4). Missing mills were also mapped in Figure 1 for the same purpose. Initial exploratory analysis suggested that the annual cumulative receipts for each mill might best be modeled by sigmoid functions, as there are two asymptotes present in the cumulative frequency, zero and one. Two types of sigmoid functions were selected to analyze the data: logistic and Gompertz functions.

Sigmoid functions are nonlinear in the parameters, and since each mill had repeated measures, this analysis is a nonlinear repeated measures design and nonlinear mixed-model procedures were employed (SAS macro NLinMix). As there were no like studies detailing a known covariance structure, the following spatial covariance models were considered: spherical, exponential, Gaussian, linear, linear log, and power (Little et al. 1996, p. 305). Models were evaluated using the corrected Aikake's information criterion (AICc) in SAS (smaller AICc is better), as well as an examination of the residuals using the 2003 data as a validation set (181 out 187 mills responded in 2003). Model terms were checked for significance at the $\alpha$=0.05 level.

### Nonlinear Model

$$\mathbf{y} = \mathrm{f}(\boldsymbol{X},\boldsymbol{\beta}) + \mathbf{e} \tag{1}$$

where

$\mathbf{y}$ = vector of mill annual cumulative frequency receipts values.
$\boldsymbol{X}$ = matrix of observed independent variable values.
$\boldsymbol{\beta}$ = vector of unknown fixed effects parameters.

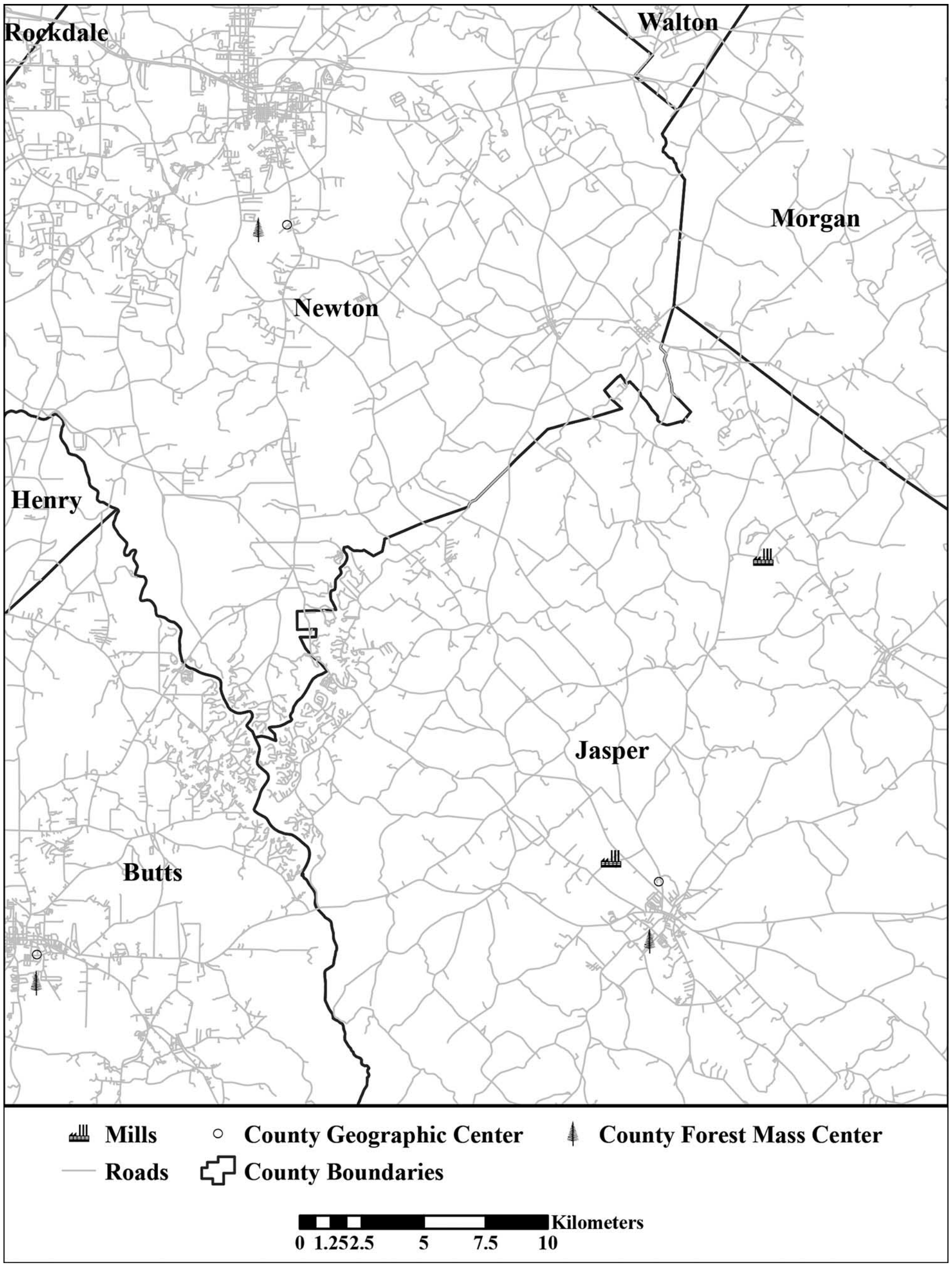


**Figure 3. Road network example. Map created by author.**

**e** = vector of random error.

f = is a function, in this case either a logistic or Gompertz function.

#### Logistic Function

$$y = \frac{1}{1 + e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1 X_2}} \tag{2}$$

#### Gompertz Function

$$y = e^{\beta_0 e^{\beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1 X_2}} \tag{3}$$

where

e = base natural log.

$\beta_0 \ldots \beta_3$ = unknown fixed effects parameters.

$X_1$ = distance.

$X_2$ = number of employees.

## Results

### Models

AICc values for the multiple distance measures under each nonlinear model form are presented in Tables 2 and 3. There was a wide range of AICc values within a model form for most distance measures. For instance, for Forest Centers using road distances to mills the AICc values ranged from −1,972.7 to 122.7 using the logistic model (Table 2) and from −1,964.8 to 90.8 using the Gompertz model (Table 3). The Geographic Center with road distances exhibited very similar ranges, −1,916.5 to 130.8 and −1,905.3 to 98.8 respectively, for the logistic and Gompertz models. The ranges on the Geographic Centers using straight line distance were slightly

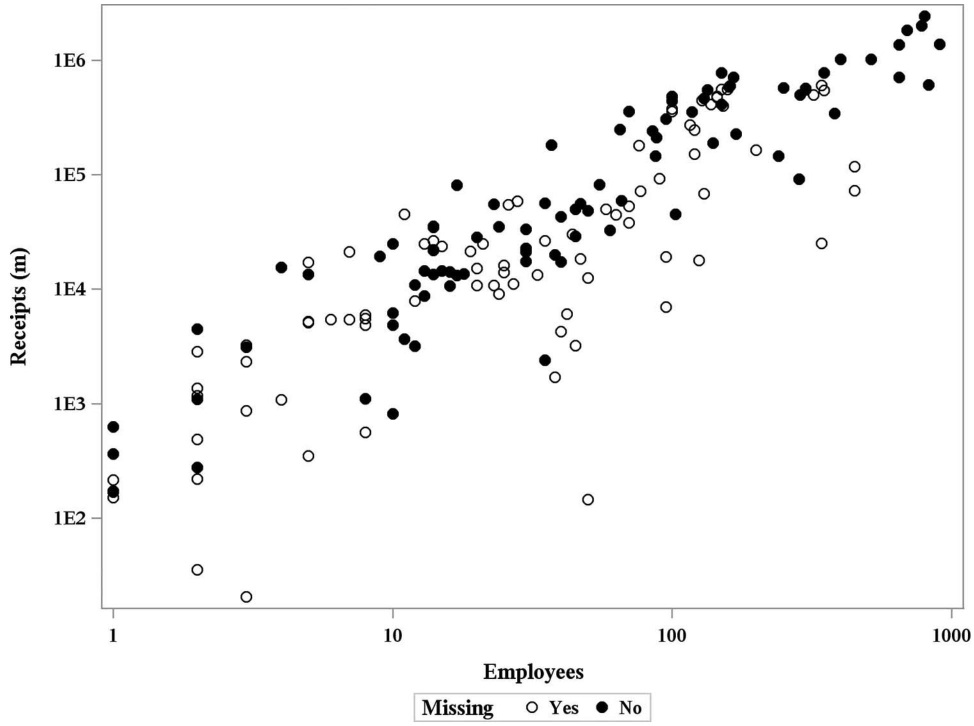


**Figure 4. Comparison of missing and nonmissing mills. Nonmissing mills data are from 2001, and missing mill data are from 1999.**

**Table 2. AICc values for logistic county center × distance model types.**

| Covariance structure | Geographic-Straight line | Forest-Straight line | Geographic-Road | Forest-Road |
|---|---|---|---|---|
| Spatial | | | | |
| Exponential | −1,851.5 | **−1,883.3** | **−1,916.5** | **−1,972.7** |
| Exponential anisotropic | 113.4 | 108.0 | 130.8 | 122.7 |
| Gaussian | 107.4 | 101.9 | 124.7 | 116.7 |
| Linear | −893.6 | −863.6 | −832.6 | −889.0 |
| Linear log | −1,756.8 | −1,809.5 | −1,830.3 | −1,862.4 |
| Power | −1,851.5 | **−1,883.3** | **−1,916.5** | **−1,972.7** |
| Power anisotropic | **−1,853.5** | −1,809.5 | −1,879.9 | −1,932.6 |
| Spherical | −1,840.9 | −1,870.2 | −1,904.3 | −1,962.7 |
| Identity | 105.4 | 99.9 | 121.3 | 114.7 |

Values in bold represent models with the smallest AICc values for that specific distance model.

**Table 3. AICc values for Gompertz county center × distance model types.**

| Covariance structure | Geographic-Straight line | Forest-Straight line | Geographic-Road | Forest-Road |
|---|---|---|---|---|
| Spatial | | | | |
| Exponential | **−1,839.5** | **−1,873.8** | **−1,905.3** | **−1,964.8** |
| Exponential anisotropic | 82.4 | 77.1 | 98.8 | 90.8 |
| Gaussian | 76.4 | 71.1 | 92.8 | 84.8 |
| Linear | −901.6 | −880.5 | −853.1 | −909.4 |
| Linear log | −1,784.2 | −1,835.6 | −1,852.7 | −1,888.9 |
| Power | **−1,839.5** | **−1,873.8** | **−1,905.3** | **−1,964.8** |
| Power anisotropic | −1,834.6 | −1,819.8 | −1,854.4 | −1,913.9 |
| Spherical | −1,830.2 | −1,863.3 | −1,895.9 | −1,956.5 |
| Identity | 74.4 | 69.1 | 89.3 | 82.8 |

Values in bold represent models with the smallest AICc values for that specific distance model.

smaller, ranging from −1,853.5 to 113.4 for the logistic models and from −1,839.5 to 82.4 for the Gompertz models. The Forest Center straight line distance models had similar ranges, −1,883.3 to 108.0 and −1,873.8 to 77.1 for the logistic and Gompertz models, respectively.

The overall "best" models in terms of AICc were road distance models, which had AICc values less than −1,900. The straight line distance models did not have values quite as small, with −1,883.3 being the least. These best models were those using the spatial exponential and spatial power covariance structures, except for one case of the logistic model using geographic centers and straight line distances.

Model selection continued by dropping models that had a nonsignificant coefficient for the interaction term of distance* employees. None of the logistic models satisfied this criterion. Data from 2003 were then used to estimate the cumulative frequency for receipts for each mill observation. This was subtracted from the actual value to generate the residual value. The mean of the residuals was calculated. Models that had confidence intervals containing zero were considered unbiased, and only models that produced unbiased residuals for the 2003 data were included for further consideration (Table 4). The mean residuals for the cumulative frequencies for all unbiased models using the 2003 data were close to zero, ranging from −0.0082 to −0.0043. Standard errors for the means were all nearly identical, ranging from 0.0054 to 0.0055.

Four Gompertz models remained that were best in terms of AICc (Table 2) and produced unbiased residuals for the 2003 data (Table 4). The spatial exponential and spatial power covariance structures produced nearly identical models within two remaining distance and county center model types: road distance to geographic centers and road distance to forest mass centers (Table 5). The spatial power covariance structure was selected to illustrate the response surfaces produced for these two model types (Figure 5A and B).

**Table 4. Residual confidence limits of the cumulative frequency of mill receipts for Gompertz models with a significant interaction term and unbiased residuals.**

| Model | Mean | Lower | Upper | S.E. |
|---|---|---|---|---|
| Geographic-Road | | | | |
| Exponential | **−0.0049** | **−0.0157** | **0.0058** | **0.0055** |
| Power | **−0.0050** | **−0.0157** | **0.0058** | **0.0055** |
| Power anisotropic | −0.0043 | −0.0149 | 0.0063 | 0.0054 |
| Spherical | −0.0064 | −0.0172 | 0.0044 | 0.0055 |
| Forest-Road | | | | |
| Exponential | **−0.0070** | **−0.0177** | **0.0037** | **0.0055** |
| Power | **−0.0070** | **−0.0177** | **0.0037** | **0.0055** |
| Power anisotropic | −0.0043 | −0.0149 | 0.0063 | 0.0054 |
| Spherical | −0.0082 | −0.0189 | 0.0026 | 0.0055 |

Values in bold represent models with the smallest AICc values for that specific distance model.

## Discussion

For this data set, the spatial exponential and spatial power covariance types were chosen as best covariance structures. These two types performed equally well within the Gompertz functional form for road distances based on either the geographic center or forest mass centers. This is not unexpected as roundwood logs are typically transported by trucks. The means for the 2003 residuals were unbiased and the standard errors were reasonable at 0.0055 (Table 4). Given that the two covariance structures produced nearly identical results and that the power type has a slightly simpler model form than the exponential, the power type is better suited for future use.

In selecting a distance type to use, both the Geographic Center and Forest Center road models performed nearly identically. The Forest-Road model had a lower AICc, while the residual mean for the Geographic Center was slightly closer to zero than the Forest Center (yet the standard errors were identical). The response surfaces produced for the two model types are also very similar (Figure 5A and B), as the models use the same functional form (Gompertz with a two-way interaction) and have very similar estimated coefficients. As would be expected, increasing the distance increases the cumulative frequency. Increasing the number of employees, however, decreases the cumulative frequency. For a given distance, larger mills (those with more employees) will have a lower cumulative frequency of receipts. Larger mills are utilizing more roundwood (on a percentage basis) from further out in distance than smaller mills.

In choosing a method to calculate cumulative frequencies, it appears equally useful to use either a forest center or a geographic center. Calculating the forest mass, however, requires a lot of additional data computation. It is much simpler to calculate a geographic center. Therefore, for future modeling work, it is recommended to use the Gompertz function in a nonlinear repeated measures design incorporating the spatial power covariance power structure with distances calculated as road distances to the geographic center of the county. This mill-centered approach differs from a recent study by Brandeis and Lambert (2014) that explores forecasting of county roundwood pulpwood production for 16 counties in Florida. There, the authors used county-vector autoregressive (CVAR) and spatial panel vector autoregressive (SPVAR) methods with counties being the observational unit. Distances were measured as Euclidean (straight line) distance between county centroids. Their methods are restricted to pulpwood production but demonstrate other possible modeling options.

For any desired cumulative frequency for receipts, the estimated model can be rearranged to solve for the road distance that achieves that cumulative frequency. This allows a procurement radius to be estimated for a mill for a selected cumulative frequency. It should be noted that this road distance to points around the mill is not a uniform circle centered on the mill as it is for the straight line distance. Roads take into account transportation obstacles, e.g., bodies of water and undeveloped land. If the procurement radius is mapped for a given cumulative frequency, the region it represents around the mill will, in all likelihood, exhibit a departure from circularity.

Gompertz function solving for distance

$$X_1 = \left[\ln\left(\frac{\ln(y)}{\beta_0}\right) - \beta_2 X_2\right] \Big/ (\beta_1 + \beta_3 X_2) \qquad (4)$$

thus,

$$\text{Distance} = \left[\ln\left(\frac{\ln(\text{Cumulative\_Freq})}{\beta_0}\right) - \beta_2 \text{Employees}\right] \Big/ (\beta_1 + \beta_3 \text{Employees}) \qquad (5)$$

### Example Case

A random mill was selected from the missing mills from 2001. Prior survey data showed that the mill had 8 employees and previous

**Table 5. Parameter estimates with confidence limits for unbiased, full parameter Gompertz models.**

| Model | Effect | Estimate | S.E. | *P* value | Lower | Upper |
|---|---|---|---|---|---|---|
| Geographic-Road | | | | | | |
| Spatial-exponential | Intercept | −3.7387 | 0.2611 | <0.0001 | −4.251 | −3.2263 |
| | Distance | −0.05546 | 0.001828 | <0.0001 | −0.05905 | −0.05188 |
| | Employees | 0.000431 | 0.000174 | 0.0136 | 0.000089 | 0.000774 |
| | Distance*employees | 0.000028 | 3.74E-06 | <0.0001 | 0.000021 | 0.000036 |
| Spatial-power | Intercept | −3.7388 | 0.2611 | <0.0001 | −4.2511 | −3.2264 |
| | Distance | −0.05546 | 0.001828 | <0.0001 | −0.05905 | −0.05188 |
| | Employees | 0.000431 | 0.000174 | 0.0136 | 0.000089 | 0.000774 |
| | Distance*employees | 0.000028 | 3.74E-06 | <0.0001 | 0.000021 | 0.000036 |
| Forest-Road | | | | | | |
| Spatial-exponential | Intercept | −3.7161 | 0.2549 | <0.0001 | −4.2162 | −3.216 |
| | Distance | −0.05558 | 0.001774 | <0.0001 | −0.05907 | −0.0521 |
| | Employees | 0.000304 | 0.000209 | 0.1454 | −0.00011 | 0.000713 |
| | Distance*employees | 0.000032 | 4.04E-06 | <0.0001 | 0.000024 | 0.00004 |
| Spatial-power | Intercept | −3.7163 | 0.2549 | <0.0001 | −4.2163 | −3.2162 |
| | Distance | −0.05558 | 0.001774 | <0.0001 | −0.05907 | −0.0521 |
| | Employees | 0.000304 | 0.000209 | 0.1455 | −0.00011 | 0.000713 |
| | Distance*employees | 0.000032 | 4.04E-06 | <0.0001 | 0.000024 | 0.00004 |

**Table 6. Example application of the Gompertz Geographic-Road distance model using a randomly chosen mill. Mill had previous annual receipts of approximately 600 m³.**

| County | State | Distance (km) | Employees | Cumulative freq | Frequency | Estimated receipts (m³) |
|---|---|---|---|---|---|---|
| | | | | . . . . . . . . .(of receipts) | . . . . . . . . . | |
| Habersham | GA | 6.0 | 8 | 0.0474 | 0.0474 | 28.44 |
| White | GA | 31.0 | 8 | 0.2743 | 0.2269 | 136.14 |
| Stephens | KY | 32.6 | 8 | 0.2935 | 0.0192 | 11.53 |
| Rabun | GA | 38.5 | 8 | 0.3680 | 0.0745 | 44.70 |
| … | … | … | … | … | … | … |
| Jackson | GA | 72.4 | 8 | 0.7312 | 0.0042 | 2.53 |
| Union | GA | 74.5 | 8 | 0.7475 | 0.0163 | 9.78 |
| Hart | GA | 76.3 | 8 | 0.7610 | 0.0135 | 8.12 |
| … | … | … | … | … | … | … |
| Whitfield | GA | 173.3 | 8 | 0.9902 | 0.0005 | 0.31 |
| Douglas | GA | 175.8 | 8 | 0.9910 | 0.0008 | 0.47 |
| Jasper | GA | 176.1 | 8 | 0.9911 | 0.0001 | 0.05 |
| Bradley | TN | 179.2 | 8 | 0.9920 | 0.0009 | 0.54 |
| Buncombe | NC | 179.9 | 8 | 0.9922 | 0.0002 | 0.12 |
| … | … | … | … | … | … | … |

… not all counties shown for brevity.

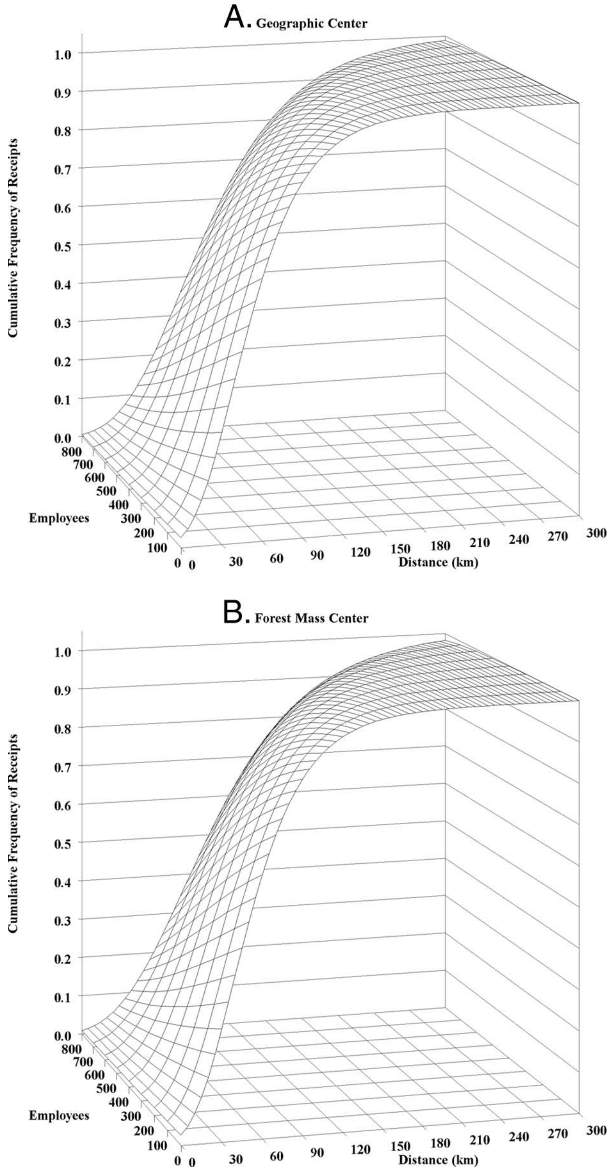


**Figure 5. Estimated cumulative frequency of receipts under two Gompertz road distance models using the spatial power covariance structure.**

annual receipts of nearly 600 m³. Suppose there is interest in a procurement radius of 75% of receipts. Using Equation 5 with a cumulative frequency of 0.75 and the estimated coefficients from the Gompertz Geographic-Road, Spatial (Power) model, (Table 6) the procurement radius is ~75 km. Any county with a distance to the mill less than this would be considered part of the procurement radius. For this mill, Union County, GA, and all the counties of shorter distance to the mill would be included; an abbreviated list is given in Table 6.

To allocate receipts to counties, the previously determined distances from the mill to the geographic centers (from shortest to longest distance) and the number of employees are substituted into Equation 3 to calculate the estimated cumulative frequencies. These data are shown in abbreviated form in Table 6 for the example mill. The frequency is arrived at by subtracting the cumulative frequency of the prior county from the cumulative frequency of the county of interest. The frequency for the county is then multiplied by the total volume of roundwood receipts for the mill to arrive at the allocation for the county. While the prior TPO survey data were used with this missing mill, the number of employees and the total receipts for the current survey may be used if these two pieces of information can be obtained.

## Conclusions

The models developed using this methodology are an important beginning step to creating distance driven receipts models for mills in the state of Georgia. Future studies limited strictly to total receipts for the mill without county-level data can be conducted if necessary. An important consideration for future TPO studies will be to collect total receipts data for a particular mill regardless of county data because models developed using these methods can then be applied to that missing data. In addition, a much-needed second stage of research will be needed to determine what factors determine harvesting in a particular county. This will help refine estimates being made for counties that may have low harvest levels, e.g., very urban counties or counties with limited percentages of forest. It is hoped that these models may also be transferable to other states, with models developed from past TPO studies.

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