ArcGIS Tool "Biomass Cost Analyst" Enhances Biomass Quantification and Forest Management in Fairbanks, Alaska (USA)

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Abstract

Fairbanks Forestry needs to provide a recently opened pellet mill with 405 hectares of woody biomass annually, at a price of 43 USD or less per ton. Is Fairbanks Forestry able to provide the required biomass? The developed ArcGIS tool "Biomass Cost Analyst" gives answers.

A price per ton of woody biomass was calculated for each timber stand. This was done by using the Fairbanks forest inventory database, by determining several cost parameters, and then processing this data with a tool created for use in ArcGIS. Development of the tool was carried out by creating a model with the ModelBuilder in ArcGIS Desktop 10. The model is composed of a main model and submodel. The submodel is necessary to facilitate the use of iteration. In addition, a python script tool was created for the submodel.

At the 43 USD per ton limit, there are approximately 24,000 hectares, with more than 2.4 million tons of woody biomass, available. The majority of the acreage is comprised of birch and aspen stands, with the strata Birch Closed 26%, and Aspen Closed 25%. Currently, the pellet mill mainly uses white spruce, of which there is only a small amount available.

1 Introduction

"Fairbanks air quality remains unhealthy" (FAIRBANKS DAILY NEWS-MINER 2011) was the headline of Fairbanks' local newspaper in January 2011. The city of Fairbanks, Alaska (USA) experiences serious air-quality problems in the winter, 60% of these being due to wood-stove smoke (FAIRBANKS NORTH STAR BOROUGH 2010). This is one of the reasons why, in the fall of 2010, a wood pellet factory started operating in Fairbanks to provide readily available pellet fuel to Interior Alaska residents. Pellets provide the cleanest burn of any solid fuel (ZHANG, et al. 2009). Other important reasons for opening the business included the rising cost of fossil fuels, the generally long heating season of up to eight months in the interior of Alaska, and the abundance of timber in the Fairbanks Area.

The factory is not yet running at full capacity, but at maximum capacity it will require approximately 405 hectares of forest stands per year (DOUSE 2010). To keep the operation economical, and to supply pellets at an affordable price, the pellet mill is willing to pay a maximum of 43 USD per ton for woody biomass (DOUSE 2010).

The Fairbanks Division of Forestry (FDOF) provides the timber to the pellet mill. Currently, demand for timber from the Fairbanks Forestry area is low. Only local loggers are customers of FDOF. The pellet mill's demand for timber is an opportunity for FDOF to

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utilize the vast amount of timber in the Fairbanks Forestry Area. In the area, forest stands are always sold as one complete unit and only the clear-cutting logging practice is applied. FDOF has to determine which forest stands they should focus on to meet the requirements of the pellet mill. In addition to this, FDOF needs to ascertain if the amount of 405 hectares of forest is available at or below the 43 USD per ton threshold. This research identifies stands FDOF should focus on, and whether or not the demand can be satisfied.

Extensive biomass cost research has been conducted. STASKO et al. (2011) developed a methodology to combine forest inventory and price data with records of competing industries to develop maps of feedstock availability. CAVALLI AND GRIGOLATO (2010) evaluated the influence of different forest road networks in northeastern Italy on the supply cost of forest woodchips. For four bioenergy plants in Denmark, MÖLLER AND NIELSEN (2007) analyzed the cost of transporting wood chips from forests to the plants, based on land cover maps and a digital road network. PUTMANN (2010) implemented a similar approach for the village of Fort Yukon in the USA by building a GIS model that estimated biomass stocking, growth, sustainability and cost. Transportation costs and the available data have been determined to be the key components of biomass cost calculation (e.g. SEARCY et al. 2007, ANTTILA et al. 2011).

The Fairbanks Forest Inventory Database was available and was the starting point for this report. This information, coupled with stumpage costs, transportation costs, harvest costs, and reforestation costs, determines the overall delivered cost for each stand. Forest practices (e.g. clear-cutting, sustainability, etc.) are considered as given and will not be the subject of this paper.

The aim of this paper is to present the development and test application of an innovative cost analysis tool in order to determine a price per ton of woody biomass for particular regional forest stands. This was done by inventing a software tool in the ArcGIS environment, which operates by allowing the input of different cost-parameters and inventory data, thereby providing the option of reproducing the results for different regions.

2 Resource Data and Data Processing

The data processing was all done with ArcInfo 10. The following empirical data and feature classes were created in a geodatabase: Inventory Feature Class; Operable Areas Feature Class; Access Points to Operable Areas Feature Class; and, Destination Feature Class.

2.1 Inventory Feature Class

FDOF keeps a constantly updated inventory database (ALASKA DNR DIVISION OF FORESTRY 2010) of the Fairbanks Forestry Area. It determines approximately 30,000 forest stands as features, spread over more than 200,000 hectares. Each feature has a value assigned for the following attributes:

- ***Stratum***: Describes the tree species composition of a forest stand. 14 different strata make up the Fairbanks forest stands.
- ***Tons per stand:*** Describes the mass of each stand's tree biomass in tons.
- ***Acres per stand:*** Describes the area of each stand in acres.
- ***Tons per acre:*** Describes the mass per area in tons per acre of each stand.

2.2 Operable Areas Feature Class

Many stands are not operable as it is currently not feasible to construct the roads and bridges necessary to access them. The operable and inoperable stands were identified by expert supervised selection (discussion with J. Douse, Fairbanks Resource Forester). Polygons, covering only operable stands, were created in a new feature class. Each area has one access point at an existing road. In addition to this, a text field named "AREA" was added to the feature class. Each area was assigned a unique name in the "AREA" text field. These fields will be re-integrated at a later point to connect the areas with the forest stand to the access points.

2.3 Access Points to Operable Areas Feature Class

An additional feature class was created, which included the access points to the operable areas at existing roads. In addition, a text field named "AREA" was added to the feature class. Each access point has the corresponding name to the operable areas assigned in the "AREA" text field. Additionally, a field named "DIST_MILES", specifying the shortest road distance from the access point to the destination feature, was added to the feature class. The distances were manually specified with the help of the ArcGIS *Find Route dialog box*.

2.4 Destination Feature Class

The last feature class that was created contains a point determining the destination (in this case, the pellet mill) that the timber is to be transported to. The pellet mill's coordinates were ascertained by entering the address into Google Earth.

2.5 Input Cost-Parameters

The following input cost-parameters were necessary: stumpage price for each stratum (per ton); price for transportation (per ton); price for harvest (per acre and per ton); and price for reforestation (per acre). These parameters are based on empirical data collected in discussion with area foresters, loggers, and wood-sellers. Development costs for infrastructure, such as road construction or internal access within individual forest stands, were not included as they are estimated individually for each timber sale by the Fairbanks Division of Forestry and lead to a reduction of the stumpage price.

Stumpage price for each stratum table
The stumpage price is the cost of purchasing timber from Fairbanks Division of Forestry. It was necessary to calculate a price per ton for each of the 14 strata; the calculation is based on the current Fairbanks Division of Forestry price list. Table 1 depicts the price list, which is automatically stored in the format of a Microsoft Excel Workbook spreadsheet. The price list categorizes timber into spruce sawlogs, spruce fuelwood, birch fuelwood, and aspen fuelwood, with each category having a price per cubic foot assigned to it. Only spruce is differentiated into sawlogs and fuelwood. Birch and aspen are both sold as fuelwood.

Table 1: Stumpage price list

Stumpage	Price [$/m^3]
Spruce sawlogs	9.18
Spruce fuelwood	1.06
Birch fuelwood	4.24
Aspen fuelwood	0.35

A second spreadsheet in the workbook contains the stratum inventory data for each of the 14 strata. The 14 strata are split up into different products based on the categories of the price list: spruce sawlogs, spruce fuelwood, birch fuelwood, and aspen fuelwood. Each product of each stratum has a total volume, and a total mass, assigned to it.

Based on the stumpage price list (see Table 1), a stumpage price per ton was calculated for each stratum separately. The cubic footage of each product was multiplied by the corresponding price in the stumpage price list and divided by the corresponding tons, resulting in a product price per ton for each stratum. In the next step, the percentage of each product in each stratum was calculated by dividing the total tons of the product by the corresponding stratum’s total tons. Finally, this percentage was multiplied by the product price, and added to the other results, resulting in a final price for each stratum per ton.

The third, and final, spreadsheet contains only the stratum and the corresponding stumpage price per ton. This information is necessary, as this spreadsheet will be input into the tool. Table 2 displays the final spreadsheet.

Table 2: Stumpage price list for each stratum

Stratum	Vegetation Description	Stumpage price [$/t]
1	White Spruce Sawtimber	14.9
2	White Spruce Poletimber	16.46
3	Birch Closed	9.08
4	Birch Open	8.82
5	Aspen Closed	0.84
6	Aspen Open	0.77
7	Birch-Aspen Closed	9.49
8	Birch-Aspen Open	3.47
9	White Spruce-Birch Sawtimber	19.75
10	White Spruce-Birch Poletimber	24.76
11	White Spruce-Birch-Aspen Sawtimber	27.02
12	White Spruce-Birch-Aspen Poletimber	26.27
13	White Spruce-Balsam Poplar	16.21
14	Black and White Spruce-Birch-Aspen	12.44

Price for transportation
The transportation price was calculated based on empirically collected interview data from local loggers and wood-sellers. On average, a logger spends 120 USD per hour per log truck, and a logger loads, unloads, and travels a distance of 53 kilometers in 3.33 hours. To load a full truckload (approximately 20 tons), transport it 53 kilometers, and unload it, costs a logger 400 USD:

3.33 h x 120 USD per hour per truckload = 400 USD per truckload

To transport one ton 53 kilometers costs 7.55 USD:

400 USD/ 20 tons = 20 USD per ton

To transport one ton one kilometers costs 0.38 USD:

20 USD per ton/ 53 miles = 0.38 USD per ton per mile

Price for harvest
The harvest price, covering the actual logging costs, was estimated based on discussion with Jeremy Douse, Fairbanks Resource Forester, and is therefore based on his personal experience. 500 USD per hectare and 10 USD per ton are the harvest costs in the Fairbanks Forestry Area.

Price for reforestation
In addition, the reforestation price was estimated, based on discussion with Jeremy Douse, to be 250 USD per hectare.

3 Tool development

The model is composed of a main model and a submodel. A script tool was created in the programming language Python 2.5. At the beginning, the main model branches into two parts, with the Inventory Features splitting into Operable Inventory Features and Not Operable Inventory Features. Next the distance from the Destination Feature to the forest stands is calculated, and finally the price calculation is done.

Operable Inventory Features
The Operable Inventory features are selected by location, based on the spatial relationship to the feature class containing the Operable Areas. Only features covered by the Operable Areas are selected and are stored in a new feature class. Following this, the new feature class is split into a subset of multiple output feature classes. Each new output feature class represents one Operable Area and stores the Inventory Features of that particular Operable Area. From here the data is processed in the submodel.

The submodel is necessary in order to make use of iteration. Iteration is similar to looping in programming and it means to repeat a process over and over. The submodel iterates each of the subsets of the new created feature classes through the following process:

1. Points are created out of the inventory polygons, representing the centroids of each stand.
2. The python script tool is applied.

3. The created python script tool selects, for the centroids of the Inventory Features iterated at that moment, the related Access Point. For example, access point A gets selected if the centroids of the inventory features of the Operable Area A are iterated through the submodel. This part of the sub-model is shown in Figure 1.
4. The straight-line distances between the Access Points and the centroids of each stand are measured in miles and added to each Operable Inventory Feature.
5. The data of the submodel is returned to the main model.

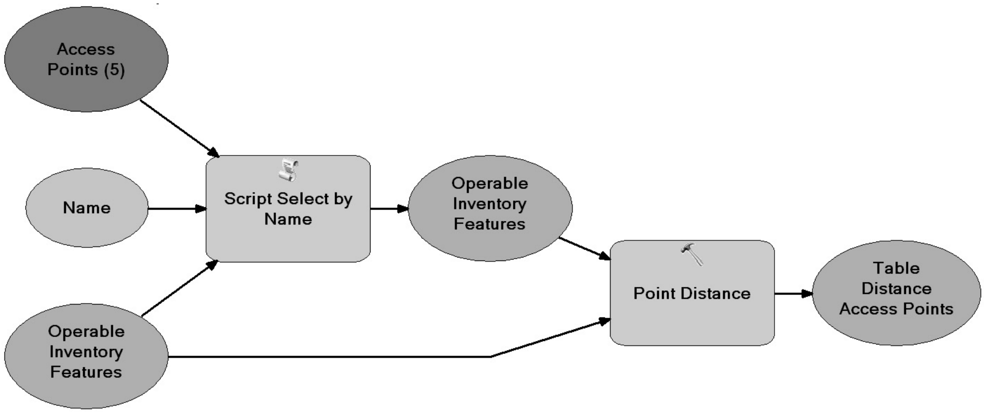

Fig. 1: Part of sub-model with python script tool

The multiple feature classes, which were iterated through the submodel, are now merged into one feature class. This feature class will now be joined to the table of the original Access Points. Each inventory stand receives, by this method, the distance between the corresponding Access Point and the Destination Feature. This distance was entered earlier in the Access Points Feature Class. Both distances, the distance Destination Feature to Access Point and Access Point to centroid stand, are now added together and stored in a new field.

Not Operable Inventory features

Parallel to the Operable Inventory Features, the Not Operable Inventory features are processed. The Not Operable Inventory features are selected by erasing the Operable Inventory features from the original Inventory feature class. The features that are not erased are stored in a new feature class, representing the Not Operable Inventory Features.

Following this, points are created out of the inventory polygon stands, representing the centroids of each stand. The straight-line distances between the centroids and the destination features are then measured in miles and added to each Not Operable Inventory Feature. The distance is then multiplied by the highest distance from an Operable Inventory Feature centroid to the destination feature, and with a factor that can be specified in the user interface. It is not possible to determine the exact distance from the destination feature to the centroids of the Not Operable Inventory Features, because no roads to these features exist. Adding the straight-line distance to the highest distance between the Operable Inventory Features and the destination features, and multiplying the result by a factor, ensures that the Not Operable Inventory Features distances will always be higher than the

Operable Inventory Features. This results in a systematic error in the price for the Not Operable Inventory Features. Yet it gives a distinction within the not-operable inventory features. The default value of the factor is set to be zero.

Final feature class

Two feature classes are created, one containing the Operable Inventory Features, the other containing the Not Operable Inventory Features. All the features now have a distance to the Destination Feature assigned. Next, the two feature classes are merged into one feature class. Following this, prices are calculated.

The transport price is calculated by multiplying the entered value per mile per ton by the previously calculated distance. The reforestation price is calculated by dividing the entered reforestation price per acre by the tons per acre of each stand. Dividing the entered harvest price per acre by the tons per acre, and adding the price per tons, calculates the harvest price. Following this, the previously created excel sheet, containing a stumpage price for each stratum, is joined with the feature class. In this way, each feature receives a stumpage price. Finally, the stumpage price, harvest price, reforestation price, and transport price are added together. For the price calculation, VB codes are used for the case zero is entered as a price. The final feature class is now created, containing a total price for each stand.

4 Results

4.1 Biomass Cost Analyst Tool

The created tool can be used in the ArcToolbox (see Figure 2). A graphical user interface (GUI) allows the user to browse for the required feature classes and the location of the geodatabase for the output. In addition, the GUI allows the user to input the timber price for each stratum (per ton); the price for transportation (per ton); the price for harvest (per acre); the price for harvest (per ton); the price for reforestation (per acre); and the factor for the not operable areas. If no price is inserted, the default price of zero USD is used.

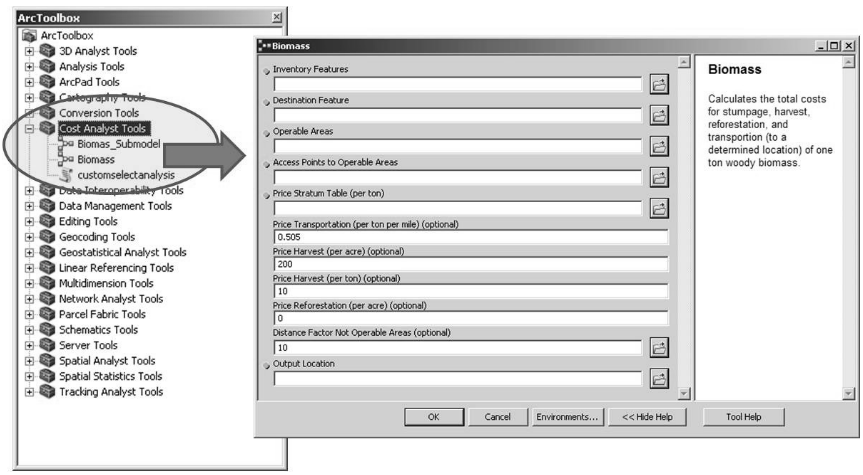

Fig. 2: Tool in ArcToolbox and GUI

4.2 Fairbanks Results

The tool creates a new feature class containing the original inventory features an additional attributes for the prices including a total price per ton for each stand. Figure 3 shows an exemplary zoom in of the Fairbanks feature class with the prices per ton for woody biomass.

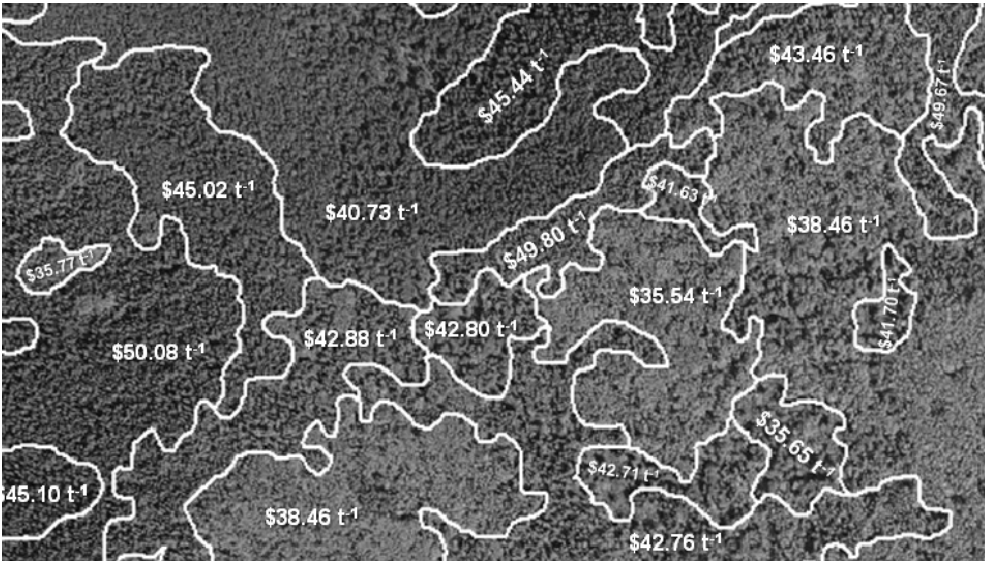

Fig. 3: Exemplary Zoom In of Biomass Price Results

From the original 30,000 stands, more than 6,000 are considered operable. These are spread over more than 50,000 hectares, and have a mass of 5.5 million tons. The price of operable stands ranges from 28 USD to 69 USD per ton. The mean of the total price of the operable stands is 46 USD per ton. All operable stands together have a total price of more than 260,000 USD.

At the price of 43 USD or less per ton, which is the price the pellet mill is willing to pay, there are more than 2,500 stands with a total of 24,000 hectares and 2.5 million tons available.

For the price of less than 43 USD per ton, the majority are closed birch and aspen stands, with *Birch Closed* at 26%, and *Aspen Closed* at 25%, followed by *Birch-Aspen Closed*, *White Spruce-Birch Sawtimber*, *White Spruce-Birch-Aspen Sawtimber*, *White Spruce-Birch-Aspen Poletimber*, and *Black and white Spruce-Birch-Aspen.*

White Spruce-Birch Poletimber, *Birch-Aspen Open*, *White Spruce Poletimber*, *Birch Open*, *Aspen Open*, *White Spruce Sawtimber*, and *White Spruce-Balsam Poplar* are only available in small amounts, representing between one and three per cent each of the total available acreage at that price.

5 Conclusion and Outlook

Even though 405 hectares of forest is currently available annually at a price of less than 43 USD per ton, it is not certain that the demand of the pellet mill can be satisfied. The majority of the stands available at the desired price are birch (Birch Closed 26%), and aspen stands (Aspen Closed 25%). At present, the pellet mill mainly processes white spruce. Less than 700 hectares of pure white spruce (White Spruce Poletimber 2.19% and White Spruce Sawtimber 0.63%) are available at the desired price, although mixed stands with white spruce amount to an acreage of about 7,500 hectares.

The pellet mill currently makes pellets out of predominantly white spruce saw timber, but the long-term availability of spruce wood at its 43 USD price limit per ton is restricted. The mill may have to be willing to pay more than 43 USD per ton for spruce; it should also explore other biomass options. This study revealed that there is only a limited supply of spruce to meet its demand. The pellet factory should consider utilizing different species (e.g. aspen or black spruce) or low quality biomass (e.g. sawdust, branches, treetops, etc.) in its production process.

The accuracy of the results of the tool can be greatly improved by empirically determining more exact transportation costs over a certain period. The estimate for the price per ton per mile is quite general. In addition, the distance from the access points to the centroids of the stands, which is currently calculated as the straight-line distance, is an ambiguous parameter without further detailed surveys.

In addition, manual data pre-processing could be more automated. For example, the determination of the distance from the access points to the Destination Features, which currently needs to be done manually, could be integrated into the tool. This is something the ArcGIS Network Analyst could be used for. Therefore, a network dataset of the street network is required as, at present, only a shapefile of the street network of the Fairbanks region exists.

The tool has also been used to implement biomass assessments in Delta Junction, Fort Yukon, and Tok Alaska. The State of Alaska has invested a considerable amount of resources into its forest inventory. The tool offers a means to utilize the forest inventory and apply it to economic feasibility studies of possible future projects that will require biomass.

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