Optimizing the location for the enterprise recycling the forestry production waste

N A Tyurin, L Ya Gromskaya*, T S Antonova, V A Kalyashov and V N Artemiev

St. Petersburg State Forest Technical University, 5, Institutsky per., 194021, St. Petersburg, Russian Federation

*E-mail: gromskaya.stl@gmail.com

Abstract. The article discusses the optimization of the location of the enterprise for recycling the wood waste from logging and wood processing industries. A promising area of waste recycling is the production of wood-fuel pellets as an alternative renewable energy source. The raw material supply of pellet production means a lot of collection activities, in which transport costs play a decisive role. Sources of raw materials and consumers of finished products are distributed over vast territories. The paper proposes an integrated approach to solving the problems of the territorial location of the recycling plant based on logistic methods and the use of geographic information systems. The paper presents a mathematical model and a technique for optimizing the territorial distribution of pellet production by the criterion of the minimum transportation costs for raw materials. The developed methodology takes into account the existing infrastructure. It involves the full use of sources of raw materials, and also allows us to choose the best option for the location of the enterprise, taking into account the social and economic possibilities of construction. The technique has great versatility, which allows it to be used to place enterprises of various fields of activity. It clearly reflects the results of the problem solution, which simplifies the decision-making process on the location of enterprises.

1. Introduction
The current level of development of logging and the woodworking industry is accompanied by the formation of a large amount of wood waste both at the stage of logging and at the stage of its processing. A promising direction for the disposal of such waste is the involvement of wood biomass in the form of wood-fuel pellets in the fuel and energy complex as an alternative environmentally friendly renewable energy source.

Location is one of the key factors affecting the competitiveness and profitability of any processing enterprise, which necessitates the development of methodological approaches to determining and justifying the place of their rational territorial distribution.

The main specific feature of pellet production enterprises is the crucial role of raw materials, their quality indicators and the territorial distribution of sources. Raw materials for such enterprises require a lot of collection activities, i.e. it is of a geographic nature, especially when using logging waste. Most of wood waste is dispersed over a large territory, which has a low transport density and a very low
development of forest infrastructure (primarily forest roads), the industrial utilization of wood waste requires a serious feasibility study. However, effective scientific methods for the territorial distribution of such enterprises with respect to sources of raw materials so far do not exist. To solve such problems of enterprise location, we advise to use universal geographic information systems and mathematical-cartographic modeling.

The purpose of the study is to develop a mathematical model and methodology for optimizing the territorial distribution of pellet production according to the criterion of minimum transportation costs for raw materials.

2. Statement of the problem of choosing the location of production

On one fragment of the map it is necessary to place one enterprise for the recycling of waste from timber industry with an installed capacity of $M$ tons per year of finished products. There is data on $n$ free sources of raw materials and their reserves $Q_i$ in m$^3$ $i = 1 \ldots n$ in the studied region. We know the output coefficients of finished products $v_i$ for raw materials of the $i$-th source, m$^3$/t. It is necessary to determine the optimal location of the enterprise by the criterion of minimum freight transport work for the delivery of raw materials, taking into account the existing transport infrastructure of the region. At the same time, the condition must be met - the location of the enterprise must be in a village or town.

3. Mathematical model and algorithm for locating a waste recycling enterprise

The methodology for the application of geographic information technologies in the solution of the problem of locating enterprises for processing waste from forestry production consists of the following sequence of steps:

1) Creating a vector map of the study area (forestry, administrative region, region). When creating a map, we must use a raster substrate to create the correct map, and also have reliable information about the geographical coordinates of the created map and its projections.

2) Collection and analysis of data on existing and potential sources of wood raw materials, their location and possible supply volumes.

3) Creation of an electronic database using the most preferred software. It is recommended to use tables created in the MS Excel table processor environment and saved in dbf format.

4) Application of information from the database to the map using the geocoding operation.

Let’s find the coordinates of the center of gravity of unused waste from the timber industry of the region $x_c, y_c$. The criterion for the search for the center of gravity of the region’s reserves is the minimum transport work for transporting waste from sources to the center of gravity. The objective function of finding the coordinates of the center of gravity is as follows:

$$ R = \sum_{i=1}^{n} Q_i 2\sqrt{(x^c - x_i)^2 + (y^c - y_i)^2} = \text{min} $$

where $Q_i$ – possible (unused) volumes of wood waste in the $i$-th source, m$^3$; $n$ - is the number of raw materials in the region; $x_i, y_i$ - coordinates of the centroid of stocks of the $i$-th source.

The obtained coordinates of the center of gravity of regional stocks of timber industrial waste allow us to obtain a basic, initial solution to the problem of locating a recycling enterprise. The main drawback of the obtained solution is not taking into account the transport infrastructure existing in the region. All transportation is provided through a direct air line (hypotenuse) and it is assumed that there is a transport connection of each source with the center, which, as a rule, is not possible even in regions with developed transport infrastructure. To take into account the transport infrastructure when searching for the location of the enterprise, we use the obtained initial reference solution of the coordinates of the center of gravity of the regional waste stocks and the geoanalysis tools in the following sequence.
Let’s map the obtained coordinates \( x^c, y^c \) of the gravity center of the stocks of regional timber waste from the region and calculate the elongation coefficients \( k_i \) of the transportation of raw materials from the centroids of their stocks \( x_i, y_i \) to the reference solution \( x^c, y^c \) of the enterprise location taking into account the existing transport infrastructure. The elongation coefficient is determined by the formula

\[
k_i = \frac{l_i^t}{l_i^v}
\]

where \( l_i^t \) – distance of waste transportation from the i-th source to the center of gravity of the reserves \( x^c, y^c \) over the existing transport network, km; \( l_i^v \) - the air distance from the centroid of the i-source reserves to the center of gravity of the reserves \( x^c, y^c \).

We determine the coordinates of the optimal location of the recycling enterprise \( x^o, y^o \) according to the criterion of minimum transport work according to the following objective function

\[
R = \sum_{i=1}^{n} k_i \cdot Q_i \cdot \sqrt{(x^o - x_i)^2 + (y^o - y_i)^2} = \min
\]

The new obtained solution on the location coordinates of the enterprise will already take into account the existing transport infrastructure, but it assumes the full use of raw materials in the region and does not take into account some social and economic possibilities of building the enterprise at the coordinates \( x^o, y^o \) (lack of settlements, heat and energy, labor). To account for these factors, we proceed to the third stage of the algorithm for finding the optimal location of the enterprise.

Using geoanalysis tools (buffering), we find the nearest (closest \( m \)) to the point with coordinates \( x^o, y^o \) settlements that satisfy the requirements for the possibility of building a processing plant and measure their coordinates \( x_j, y_j, j=1...m \) in a GIS project. The coordinates will be promising options for locating a processing plant there. To determine the optimal one, we proceed to the fourth stage of the algorithm.

For each j-th variant of enterprise location, the problem of optimizing the supply of raw materials from the i-th source \( q_i \) is solved by the criterion of minimum transport work. Objective function

\[
R_j = \sum_{i=1}^{n} k_{ij} \cdot q_{ij} \cdot \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} = \min
\]

Limited by

\[
\sum_{i=1}^{n} q_{ij} = M
\]

\[
q_{ij} \leq Q_i, \quad i=1,2...n, j=1,2...m
\]

\[
q_{ij} \geq 0, \quad i=1,2...n, j=1,2...m
\]

where \( R_j \) – optimal transport work on the delivery of raw materials of the j-th variant of the enterprise location, m³ * km; \( q_{ij} \) - the volume of supply of raw materials from the i-th source to the j location of the enterprise, m³; \( k_{ij} \) is the elongation coefficient for the transportation of raw materials from the i-th source to the j-th variant of the enterprise location taking into account the transport infrastructure (2); \( M \) - the capacity of the processing enterprise for the production of finished products, tons; \( v_i \) - the coefficient of output of finished products for raw materials of the i-th source, m³ / t ; \( Q_i \) - the possible volume of supply of raw materials of the i-th source, m³.

The objective function (4) determines the total freight work for the transportation of raw materials. Expressions (5) and (6) determine the balance between the required volume of raw materials and the presence of its reserves at collection points. Restriction (7) reflects the condition of non-negative supply volumes of raw materials.
The final version of the territorial location of the enterprise is selected according to the criterion of minimum transport work from \( j \) options \( j=1,2,...,m \). From \( m \) places, we choose a place for which the value of \( R_j \) is minimal. As a result, we get the address of the location of the enterprise, after which we should evaluate the feasibility of locating the enterprise in the selected village. If it is impossible to place the enterprise in this place, then it is excluded from consideration and the place with the smallest sum from the remaining options is determined. This procedure is performed until a solution is found.

The problem of the optimal location of the pellet production plant can be solved using the non-linear programming method in the MS Excel add-on “Solution Search” and geographic information technologies in the following sequence:

1. By solving the optimization model (1), we find the coordinates of the optimal position of pellet production without taking into account the existing transport network.
2. The obtained coordinates of the station \( x_0, y_0 \) are mapped and the elongation coefficients are calculated taking into account the use of existing roads of the region for the delivery of logging waste according to formula (2).
3. Once again, we calculate the optimal station coordinates using the optimization model (3) and map the point of the position of the pellet plant now taking into account the existing transport network of the region.
4. Near the point of the found optimal position of pellet production, all settlements are considered for the possibility of placing a pellet production plant. For each location of the enterprise, the problem of optimizing the supply of raw materials by the criterion of the minimum transport work (4-6) is solved and the final decision is made.

The performed machine experiments confirmed the reliability of the proposed methodology, which can be recommended for optimizing the territorial location of wood waste recycling enterprises according to the criterion of the minimum transport work for the delivery of raw materials.

4. Conclusion
The developed technique has great versatility, which allows it to be used to locate the enterprises in various fields of activity. The methodology also cartographically clearly reflects the results of problem solution, which simplifies the decision-making process on the location of enterprises.

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