SPATIAL MODELING IN LOGISTICS DECISION-MAKING PROCESSES.
IDENTIFYING THE OPTIMAL LOCATION FOR A SINGLE CENTRAL WAREHOUSE

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In the context of the EU single market formation it was observed a trend of giving up local deposits in favor of central regional warehouses. Another factor favoring centralization of storage is the economic crisis that has forced the need for efficient activity by making decisions on reducing costs. The first part of this paper focuses on literature review and presentation of the most important decision-making models developed in the field of logistics. Several models were selected and analyzed in detail to build a modern research methodology, based on precise mathematical calculations.

In the decision making process of selecting an optimal location for a central warehouse, we used a series of mathematical models to identify the exact geographical position, which induces minimal cost for transportation to consumption points.

In the second part of the paper, the article aims to identify the optimal location for a central warehouse in Romania.

In this methodology, we chose 100 cities in Romania, positioned throughout the country and characterized as input by three sizes: latitude, longitude and population size. Latitude and longitude were used for graphical representation of the space considered (Romania) by individual points (cities), and the population was used as approximation of the demand for generic products. We applied a mathematical model in order to calculate the gravitational center using an excel spreadsheet. Each step in applying the model is explained in detail in the paper. The results of the research indicate the optimal location (characterized by its latitude: 45.469408 N and longitude: 25.630817 E) for placing a central warehouse that can supply the 100 cities with minimal transportation costs. Were also calculated the distances between the optimal location and the 100 cities and then identified 10 cities, the closest to our optimal location (Sinaia, Sacele, Brasov, Campina, Campulung, Ploiesti, Fagaras, Pitesti, Miercuria-Ciuc, Odorheiu Secuiesc). Any of these cities can be chosen as location to build a central warehouse in Romania, because they represent a relatively good approximation for the gravitational center identified in the model applied.

Keywords: logistics, decision making process, optimal location, warehouse, spatial modeling

JEL Codes: C21, C23, R31

1. Introduction

At the microeconomic level, there are several categories of decisions to be taken for the development in terms of efficiency of economic activity of the company. These categories refer to:
- Choice of locations for production and distribution (storage)
- Establishment of production and inventory levels
- Selecting the way for transport, routes and shipment size

All these decisions can be taken on short, medium and long term. In general, decisions about production and storage location are taken for long term (5-10 years) and those related to transport routes and size expedition on a short time horizon. Every decision belongs to a specific market
with its own supply and demand (the company's product market, transport market, the market for storage space) and the effects of decisions are interconnected. Models have been developed to deal with one of these categories of decisions, but complex and dynamic models attempt to provide a long-term interaction of each decision and the related markets.

2. Literature Review
The decision-making process regarding the way of transport has been incorporated into theoretical models, which can be classified by type of strategic decision to be taken, which may be concerning the supply, production, transportation or distribution.

2.1 Decisions related to sales and supply
The two functions of the firm, supply and sales have a spatial interaction: at the aggregate level this type of models are used to calculate the exchange of goods between regions. Depending on the assumptions of the decision process at individual level, there are two types of spatial models:
- Linear programming models (LP models), in which decision making is based on the determination of alternative relationships, this model is applicable to individual firms, but cannot be applied for predicting the behavior of a large number of carriers in the business of transport of generic goods (Harker, 1988);
- Gravitational models that assumed that decision-making occurs in random utility terms (random utility conditions); models derived from this class use behavioral principles related to profit maximization model for interpreting the decision variables (Linneman, 1966);

2.2 Models related to logistics and storage services (inventory models)
In order to ensure product availability according to demand conditions, a temporary storage is needed. Ensuring the optimal functioning of a production process or the supply with different types of products according with market demands is performed using storage models (Trandafir, 2004).

Using traditional storage models (conventional inventory model) provides an optimal inventory policy.
To find the optimal balance between stock size (which involves storage costs) and quantity of individual supply/delivery (involving transport costs) information on shipping is necessary, as well as the size and frequency. This way we can determine storage and related costs, in terms of actual costs and opportunity costs.
The inventory model is based on data regarding product logistic characteristics (amount, method of packing, size of shipments, volatility of demand). The necessary time for transport, and its security are essential variables in inventory models, so the choice of route and transport modality should be integrated into the model. In some models the choice of location and size of deposit is not a decision variable (Stada and Hauwert, 1992).

3. Research Methodology
The methodology used for the empirical research in this article is based on selected elements from different models listed below.

3.1 Modeling the decision regarding the mode of transport
The decision regarding the mode of transport used for delivery can be made either by the seller or the buyer, either by forwarding company, for the sender or recipient.
Regarding the reference delivery quantity for which a decision is made there are two different approaches. A first type are models that take into account delivery units at individual shipments level or total amount delivered over a certain period of time (classified according to product type and point of origin/destination). Decisions are taken in the context of minimizing the costs of
storage and transportation, and the size and frequency of delivery are considered fixed in the model input (Di Gangi et al., 1994; Montella et al., 1994). Another type of models is those with a logistic approach of choosing the mode for transport, which takes into account simultaneously the decision regarding the size and frequency of delivery. In general delivery unit of reference in this case is considered annual. Models of this type have been developed at MIT (Freight Transportation Group, 1980; Vieira, 1992). Nuzzolo and Russo (1998) developed a logistic decision making model for choosing the mode for transport, which takes into account specific delivery units for different types of transport.

### 3.2 Models for minimizing the aggregate transportation cost

This model is based on linear programming problems, which is based on certain hypotheses, including:

- We consider m supply centers (warehouses) and n points of consumption (stores)
- For simplicity, we consider a single product, which is found in the amount \( a_i \) at the warehouse \( i \) and the quantity \( b_j \) is required in the shop \( j \), where:
  
  \[ 1 \leq i \leq m \quad \text{si} \quad 1 \leq j \leq n \]
- The cost of transporting a unit of product from warehouse \( i \) to store \( j \) is \( c_{ij} \), and it does not depend on the amount transported

The methodology for building the model is the following:

- \( x_{ij} \) denote the unknown quantity of product that will be transported from the warehouse \( i \) to the store \( j \)
- We express the required amount of product from the warehouse \( i \) to all the \( n \) stores:
  \[ a_i = x_{i1} + x_{i2} + \ldots + x_{im} \quad (1) \]
- We express the quantity transported from all the \( m \) warehouses to store \( j \):
  \[ b_j = x + x + \ldots + x = \text{quantity required at store } j \quad (2) \]
- The cost of transport for the whole amount of product is \( c_{ij} x_{ij} \)

Conditions:

- Total cost of transport from all \( m \) deposits to all \( n \) consumption centers is:
  \[ \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \quad (1) \]

In order to realize the transport it is necessary that:

\[ \sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j \quad (2) \]  

(equilibrium condition)

The system of equations (1) and (2) has an infinity of solutions, of which we are interested in those with the minimum cost of transport. In order to obtain it, we built a linear transport program:

\[ \min \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \]

\[ \sum_{j=1}^{n} x_{ij} = a_i, \quad 1 \leq i \leq m \]

\[ \sum_{i=1}^{m} x_{ij} = b_j, \quad 1 \leq j \leq n \]

\( x_{ij} \geq 0 \)

Solving this linear transport problem is accomplished using specialized software that obtains the solution / solutions that lower the total cost of transport induced by the transport of goods from warehouses to points of sale. Similar models can be built to find solutions that minimize the cost of raw material supply for production centers. The model may be complicated by adding additional conditions (constraints), such as a minimum amount that can be ordered, or different price depending on the size of delivery.
3.3. Modeling decision on choosing the location for production and storage centers
The location of factories and warehouses is an essential problem in the firm’s logistics strategy. One way of constructing such a model is based on the transport problem, which starts from the assumption of fixed supply and consumption and the solution must minimize the cost of transportation between origin and destination points (Ballou, 1999).
In order to build a simple gravity model we need a map with points of consumer demand (defined by latitude and longitude). The model will identify the optimal location solution for a central warehouse, with the lowest costs for transportation between the storage and consumption points.
Newest approaches performed a combination of cost minimization model and a gravitational model with double restriction. This model allows to set customer service level requirements (for example, imposing a maximum delivery time of 24 hours or less) as an additional restriction on the choice on optimal locations (Wilson, 2008).
The doubly constrained gravitational model uses a matrix that contains the centers of production and consumption. The matrix is used as basis to build a linear programming model that approximates the optimal flows between these locations.
Chicago Consulting (2003) applied such a model for the entire territory of the United States and identified the optimal location for a single central store in the city of Bloomington Indiana. The model took into account the possibility of adding additional storage (up to 10), each store added reducing transit time to customers.

**Figure 3: The optimal locations for placement of deposits in U.S.**

![Graph showing lead time in days to customers vs. number of warehouses.](image)

*Sursa: Chicago Consulting, “The 10 Best Warehouse Networks 2003”,
http://www.chicagoconsulting.com/10best.shtml2003*
We can observe in Figure 3 that as an extra storage is added to the model the delivery time (in days) decreases.

4. Case study: determining the optimal location for a central warehouse in Romania
In order to build a model for determining the optimal location for a central warehouse and apply it, we selected 100 towns in Romania and found their geographical position data by latitude and longitude coordinates. Based on a table in Excel with all the details, the geographical coordinates were transformed in decimal numbers using the excel formula:

```
TEXT (ROUND (LEFT (F5, 3) + (MID (F5, 5, 2) + RIGHT (F5, 5) / 60) / 60.6), "00.000000")
```

So we created a new table with decimal numbers based on which we made a graph that illustrates all selected cities.

**Figure 4: Spatial distribution of 100 selected cities in Romania**
To determine the geographic coordinates of the gravity center, we used the formula:

\[
\begin{align*}
\text{Lat}_{cg} & = \text{________} \\
\text{Long}_{cg} & = \text{________}
\end{align*}
\]

\(\text{Lat}_{cg}\) – latitude of the optimal gravitational point
\(\text{Long}_{cg}\) – longitude of the optimal gravitational point
\(P_i\) – population of the city \(i\)

To exemplify, we present a sample of the excel table used, representing the top 5 cities listed in alphabetical order.

<table>
<thead>
<tr>
<th>City</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abrud</td>
<td>23.0833</td>
<td>46.3167</td>
<td>6803</td>
</tr>
<tr>
<td>Aiud</td>
<td>23.7333</td>
<td>46.3167</td>
<td>28909</td>
</tr>
<tr>
<td>Alba-Iulia</td>
<td>23.6500</td>
<td>46.1333</td>
<td>66369</td>
</tr>
<tr>
<td>Alexandria</td>
<td>25.4000</td>
<td>43.9500</td>
<td>50591</td>
</tr>
<tr>
<td>Arad</td>
<td>21.3333</td>
<td>46.1667</td>
<td>172827</td>
</tr>
</tbody>
</table>

The city's population was taken from the data made available according to the latest census in Romania.

After calculations, we have identified the point coordinates (lat 45.469408 N, 25.630817 E long), which represents the optimal location for placing a single central warehouse that provides lower costs for product distribution in the 100 selected cities from Romania.
5. Research results and conclusions
We can observe that the nearest villages are: Sinaia, Predeal, Brasov.

In order to determine the optimal location and distances of all other cities we used the following algorithm:

\[ R = \text{earth’s radius (mean radius = 6,371km)} \]
\[ \Delta \text{lat} = \text{lat}_2 - \text{lat}_1 \text{ (latitude difference)} \]
\[ \Delta \text{long} = \text{long}_2 - \text{long}_1 \text{ (longitude difference)} \]
\[ a = \sin^2\left(\frac{\Delta \text{lat}}{2}\right) + \cos(\text{lat}_1)\cos(\text{lat}_2)\sin^2\left(\frac{\Delta \text{long}}{2}\right) \]
\[ c = 2\cdot\text{atan2} \left( \frac{\text{atan2}}{sin^2}, \frac{\Delta \text{long}}{2} \right) \text{, atan2 = excel function} \]
\[ d = R \cdot c \text{, the distance between two points, first with lat}_1 \text{ and long}_1 \text{ and the second with lat}_2 \text{ and long}_2. \]

We choose only the top 10 cities, the closest to the location for a single central warehouse.

<table>
<thead>
<tr>
<th>City</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Population</th>
<th>Estimated distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinaia</td>
<td>25.5500</td>
<td>45.3500</td>
<td>14636.0000</td>
<td>16.0248</td>
</tr>
<tr>
<td>Sacele</td>
<td>25.6833</td>
<td>45.6167</td>
<td>29967.0000</td>
<td>17.3756</td>
</tr>
<tr>
<td>Brasov</td>
<td>25.5833</td>
<td>45.6333</td>
<td>283901.0000</td>
<td>18.9675</td>
</tr>
<tr>
<td>Campina</td>
<td>25.7500</td>
<td>45.1667</td>
<td>38758.0000</td>
<td>36.1595</td>
</tr>
<tr>
<td>Campulung</td>
<td>25.0500</td>
<td>45.2833</td>
<td>38285.0000</td>
<td>67.7832</td>
</tr>
<tr>
<td>Ploiesti</td>
<td>26.0833</td>
<td>44.9500</td>
<td>232452.0000</td>
<td>76.5609</td>
</tr>
<tr>
<td>Fagaras</td>
<td>24.9667</td>
<td>45.8000</td>
<td>35759.0000</td>
<td>82.4518</td>
</tr>
<tr>
<td>Mioveni</td>
<td>24.9333</td>
<td>44.9555</td>
<td>35849.0000</td>
<td>96.2896</td>
</tr>
<tr>
<td>Mierucurea-Ciuc</td>
<td>25.8000</td>
<td>46.3500</td>
<td>41852.0000</td>
<td>99.6575</td>
</tr>
<tr>
<td>Odorheiu Secuiesc</td>
<td>25.3500</td>
<td>46.3500</td>
<td>36948.0000</td>
<td>102.7237</td>
</tr>
</tbody>
</table>

Any of these cities can be chosen as location to build a central warehouse in Romania, because they represent a relatively good approximation for the gravitational center identified in the model applied.
6. Acknowledgements
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