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Țarțavulea (Dieaconescu), Ramona Iulia; Belu, Mihaela Gabriela; Paraschiv, Dorel Mihai; Popa, Ioan

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Spatial Model for Determining the Optimum Placement of Logistics Centers in a Predefined Economic Area

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SPATIAL MODEL FOR DETERMINING THE OPTIMUM PLACEMENT OF LOGISTICS CENTERS IN A PREDEFINED ECONOMIC AREA

Ramona Iulia Țarțavulea (Dieaconescu)[1*], Mihaela Gabriela Belu[2], Dorel Mihai Paraschiv[3] and Ioan Popa[4]

[1) 2) 3)4)] *Bucharest University of Economic Studies, Romania*

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Abstract

The process of globalization has stimulated the demand for logistics services at a level of speed and increased efficiency, which involves using of techniques, tools, technologies and modern models in supply chain management. The aim of this research paper is to present a model that can be used in order to achieve an optimized supply chain, associated with minimum transportation costs. The utilization of spatial modeling for determining the optimal locations for logistics centers in a predefined economic area is proposd in this paper. The principal methods used to design the model are mathematic optimization and linear programming. The output data of the model are the precise placement of one up to ten logistics centers, in terms of minimum operational costs for delivery from the optimum locations to consumer points. The results of the research indicate that by using the proposed model, an efficient supply chain that is consistent with optimization of transport can be designed, in order to streamline the delivery process and thus reduce operational costs.

Keywords: logistic model, decision-making process, supply chain, optimal location, mathematical modeling, linear programming.

JEL Classification: C21, C23, R31

Introduction

International logistics plays an important role in the process of economic globalization and linking the national markets into a global network, providing methods, tools and systems by which goods and services can be delivered to international customers from all over the world.

*Corresponding author, **Ramona Iulia Țarțavulea (Dieaconescu) –** ramona.tartavulea@yahoo.com

This paper is in the area of academic research with practical application. The main purpose of this paper is to design a model that can be used as an instrument in the decision-making process for the domain of logistics strategies.

We aim at presenting a model that can be used by managers/shareholders/investors in the decision-making process regarding the placement of logistic facilities that would ensure the minimum transport cost to the consumption points. By using this model to design a supply chain, we ensure the premises for minimum transportation costs. The applicability of the model refers to predefined economic area, consisting of all the consumption points which are targeted to be supplied by a company. The model uses a series of mathematical methods and classical algorithms, but the element of originality consists of defining a new conceptual framework for identifying the optimal location of logistics centers, so transportation can be more efficient. The first version of this model was presented in the thesis "International logistics strategies. Modeling of logistics decision-making process„ (Țarțavulea, 2011).

1. Literature review

The literature review is focused on a few categories of models that apply in logistics, highlighting the hypothesis, algorithms, area of applicability and results. The most relevant models that have served as a point of reference in building the research methodology for this paper are presented and analyzed.

1.1. The route optimization models

The decisions regarding the choice of routes are taken in terms of cost minimization, considering the frequency and quantity of delivery as input data (Di Gangi, Montella and Russo, 1994). Further development consists in including the quantity and frequency of delivery as variables to be determined as results of the model. This type of models has been developed at Massachusetts Institute of Technology (MIT).

Nuzzolo and Russo have designed a model used in the process of deciding the mode of transport, taking into consideration delivery units that are characteristic for different types of transportation (Nuzzolo and Russo, 1998).

The problem of choosing the shortest route between multiple points is solved by the classic algorithm of Dijkstra (Trandafir, 2004), that allows the calculation of the shortest paths from one point s to all vertices x of a connected graph, the solution representing the optimum route for transportation. A simple example of how this algorithm functions is presented in figure no. 1 that illustrates a connected graph formed by 7 points linked by routes which have the necessary transit time mentioned above each one.

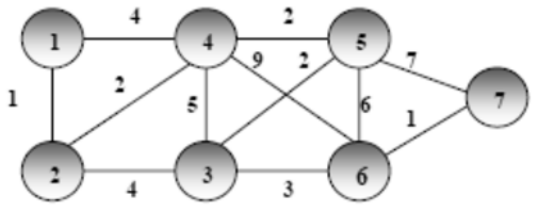

Figure no. 1: A connected graph with 7 points and the time necessary to travel between them

If we note the departing point with s, taking values from 1 to 7, we can determine the optimum route between s and any other point noted with x, where $x \in X$ and X = {the lot of all points (1-7) excluding s}.

We use the notations:

L(x) = l(s, x) = the length of the route from x to s

M(x) = set of nodes incident to node x

We initially consider L(x) =0 and the lot S = {s}, that is only the departure point.

Step 1: For any $x \in X\text{-}S$ if $x \in M(x)$ then L(x) = l(s, x), if not $M(x) = +\infty$

Step 2: Repetitive iteration.

We determine $y \in X - S$ so that L(y) = min l (z), where z doesn't belong to the lot S.

If $L(y) < \infty$ then $S = S \cup \{y\}$

For $z \in M(y)$ L (z) = min {L (z), L(y) +l (z, y)} repeated until S=X OR $L(y) = \infty$

The iteration stops when finally set S will contain all points (from 1-7) and L (x) will be equal to the minimum path from s to point x. The solution is the optimum path that consists of arcs chosen in our case with the condition of a minimum sequence of points in the route: 1, 2, 3, 6, 7.

1.2. Spatial models

The simplest model in this category is based on the method of determination for the gravitational center. A gravitational model uses a map containing the points of consumption (defined by latitude and longitude). The solution of the model identifies the optimal location for placing a central warehouse that implies minimum costs for transportation to all the consumer points.

We can complicate this model by adding more than one logistic center to the expected result of the model. The gravitational model can no longer be used after determining the first optimal location. Latest research performs a combination of a cost minimizing model and a gravity model with dual restriction. This type of model allows setting a certain level of customer service as additional restriction for establishing the optimal locations (Wilson, 2005). The interesting point made in this paper is the fact that the average delivery time can be calculated and used as a measure for the level of customer service a company aims to offer.

A gravitational dual restriction model uses a matrix that includes logistic facilities and centers of consumption. On this basis we can design a linear programming model that approximates optimal flows between these locations (Țarțavulea, Belu and Dieaconescu, 2011).

Previous research on this subject (Țarțavulea, Belu and Dieaconescu, 2011; Țarțavulea, 2015) used a gravitational model in order to identify one optimum location for placing a central logistic facility, taking into consideration the points of consumption. The aim was to minimize the global transport costs for a company. This article further develops the methodology aiming at solving the complex problem of identifying several optimal locations for placing logistics centers, taking into consideration the ones previously determined, with the purpose of obtaining the lowest cost of delivery to all the point of consumption taken into consideration.

1.3. Dynamic models

The component that incites our interest from this type of models is that of space representation. In order to be able to use the space dynamically, you need to divide it into small pieces that give the possibility of easily using it in a model. The potential of space celularisation method in mathematic modeling was first brought to light by Tobler (1979) and further developed by Phipps (1989) and Constanza, Sklar and White (1990).

The literature review also revealed that a broad base of methodologies was developed for modeling logistic processes (static scenarios comparison, dynamic simulation, mathematical optimization).

- Static Scenario Comparison - include making calculations based on data related to supply-delivery chain, without taking into account their variability over time. For this reason, data collection is relatively easy. Models of this type can be implemented through applications based on worksheets (spreadsheets). They allow static analysis, but rapid alternative scenarios (Chwif, Barretto and Saliby, 2002)

- Dynamic Simulation - this type of models capture the evolution of the system over time and thus the planning horizon can be quite large, taking into account the influences of characteristic different periods (e.g. economic cycles, seasonal variations). Stochastic effects are presented so that the degree of realism increases. The effort to collect data on flows of goods and materials, and information is greater than in the first case (Seidel, 2005).

- Mathematical Optimization - It is centered on the analysis and modeling of the logistics system. Models can be applied to a single period (single-period) or more (multi-period). Mathematical optimization is based on expressing system restrictions using equations, followed by applying specific algorithms for solving them and finding the optimum solution (Seidel, 2005).

2. Research methodology

After gathering information about logistics modeling from the literature review, it was decided to design a model that can be used in the decision-making process regarding the logistic activity and strategy of the company.

As it is defined, the model can be included in the following categories: a) by the input data and output data: spatial, gravitational; b) by the methodology used for modeling the logistic processes: mathematical optimization, dynamic simulation.

2.1. Conceptual framework

2.1.1. Input data

The input data consists of the geographic coordinates for 100 points of consumption, which delimitate an economic area; the demand in each consumer point was estimated. In order to simplify the process, it was decided to use the population as a measure of demand in each city (a city = a point of consumption).

The data regarding the geographic coordinates and population of cities were collected from public databases (Wikipedia).

Starting from the research up to date in the field of logistic modeling, modern methods were used for designing the model that can determine the optimum locations for logistics centers based on the demand from the consumption points, with the condition of minimum transportation costs. Some of the methods taken into consideration were: celularisation of space, mathematic algorithms (such as Dijkstra's algorithm), geometric methods (such as the determination of the gravitational center) and linear programming. A unique combination of these methods leads to the construction of a new logistic model, tested on the economic territory of Romania.

2.1.2. Hypotheses of research

The *hypotheses of research* are:

1. Using modeling on the logistics decision-making processes leads to lower operational costs and improvement in efficiency for the enterprise;

2. Optimal locations for storage / production for a market defined by the points of consumption can be determined using mathematical modeling and linear programming;

3. Optimal location of storage sites in the space defined as the consumer market, determines the minimum cost of transport;

4. The average time of delivery will decrease with the addition of more optimal locations.

Note: throughout the paper the logistics centers will also be referred to as warehouses, or storage locations. The functions that they can undertake can be storage of goods, production activities, packing, promotional improvements or labeling and any kind of logistics activities.

2.1.3. The structure of the model

The general structure of the model is presented in table no. 1, and it shows the main and secondary variables, as well as the input and output data, with technical specifications.

Table no. 1: The variables of the model

Main variables	Secondary variables	Technical specification
Input variables		
A geographic region		
n consumption points (c1, c2 ...cn)	Geographic coordinates	Longitude
		Latitude
	Demand on each point	May be approximated by population
Output variables		
A central warehouse DC1	Geographic coordinates	
	Number of served cities	
	Served population	
	The average delivery time	
m secondary/local warehouses (D2, D3, ... Dm)	Geographic coordinates	For the practical application m ϵ {2;10} For further development the number of local warehouses can be increased
	Number of served cities	
	Served population	
	The average delivery time	

Source: Adapted after Ţarţavulea R.I., 2015

The input data refers to geographic coordinates of points (cities, consumption centers – which define the area of application for the model) and population afferent to these.

2.1.4. Assumptions of the model

The *assumptions of the model* are:

- Any product can be delivered through a single transport;
- The cost of transportation depends on the distance between the nearest warehouse and the point of consumption (the curvature of the Earth is not taken into account);
- An average speed is taken into account, generally valid for any route;
- A consumer center will be served only by one deposit;
- The first location identified, corresponding to the center of gravity, will be considered the central warehouse, which will supply the other locations (identified by repeated simulations);
- The average delivery time will decrease with the addition of more optimal locations;
- The model does not consider the supply of raw materials to the central warehouse;
- Decision behavior is considered to be economically rational.

2.2. Design of the model

The model is structured into stages, which are presented subsequently. Please note that the first stage of the model undertakes the method used in previous papers (Țarțavulea, Belu and Dieaconescu, 2011; Țarțavulea, 2015), and the next stages represent a further original development of the model.

Stage I: Defining the geographic and economic area selected for the application of the model

Choosing the geographic region for which we want to determine the optimum location/s for placing logistic centers.

Selecting a number of points of consumption to be taken into account for products delivery (n=100 is proposed for the practical application). Each point shall be defined by its geographic coordinates (latitude and longitude) and by the estimated demand (it can be approximated by market studies or in order to simplify, we can use the population number).

Stage II: Identifying the optimum location for one central warehouse, assuring the lowest total cost of delivery to all points of consumption.

First, we need to transform the geographic coordinates into decimal numbers, in order to be able to utilize them in calculations. This is carried out by using a Microsoft Excel formula (Țarțavulea, Belu and Dieaconescu, 2011). We calculate the geographical coordinates for the gravitational center of the consumer points we defined, by using specific formulas (Țarțavulea, 2015). We obtain the optimum position for a central repository in the defined region, which is determined by the latitude and longitude calculated in Step 2, resulting in

point DC1 (the gravitational center of the defined consumer points). We calculate the distances from the central warehouse (DC1) to each point of consumption, which are required for Stage V. To determine the distances between the optimal location and all other cities have used a mathematical algorithm (Țarțavulea, Belu and Dieaconescu, 2011).

For each point of consumption we determine the average delivery time, calculated using the formula:

$$T_i = d_i * v \quad (1)$$

where:

T_i - estimated delivery time from the warehouse to every point of consumption;
di - the distance from the central warehouse to the point of consumption i;
v - the average speed applicable in selected geographic region.

Stage III: Determining the second optimal location for placing an additional secondary logistic center.

The geographical space is divided into z cells. The smaller the cells are (meaning higher number of cells) the more exact the approximation algorithm will be and the estimated solutions for the secondary storage will approach optimum placement.

For the first cell the sum of the distances from this cell to each point of consumption is calculated according to the formula:

$$s_1 = \sum_1^n dmin_{1i} \quad (2)$$

where:

s_1 - the sum of distances from the first cell to each consumer point;
d_{1i} - distance from cell 1 to the consumer point *i*, *i* ϵ {1, 2... 100}, *i* ϵ N;
d_{ci} - distance from the central warehouse to the consumer point *i*, *i* ϵ {1, 2... 100};
$dmin_{1i}$ - min (d_{1i}, d_{ci}) that is the minimum between the distance from cell 1 to the consumer point *i* and the distance from the central warehouse to the consumer point *i*.

If considered the fact that for the consumer point with a higher demand, more than one transport is necessary, then the distance should be weighted with the level of demand, modifying the formula:

$$s_1 = \sum_1^n dmin_{1i} * \frac{c_i}{c_M} \quad (3)$$

where:

c_i - the level of demand in the consumer point *i;*
c_M - the average demand, calculated as:

$$c_M = \frac{\sum_1^n c_i}{n} \quad (4)$$

Since the secondary warehouse will be supplied from the central repository, the length of the road between the two locations must be added, weighted by the volume of demand which the secondary deposit serves. The formula is amended as follows:

$$s_1 = \sum_1^n dmin_{1i} * \frac{c_i}{c_M} + d_{1c} * (1 + \frac{c'_1}{c_T}) \quad (5)$$

where:

d_{1c} - the distance from cell 1 to the central warehouse

$$c'_1 = \sum_1^p c_i \quad (6)$$

where:

$c_i \in \{1, 2... p\}$, the set of consumer points that can be served by cell 1, that is they fit the condition: $dmin_{1i} = d_{1i}$;

c_T - total demand for consumption in all consumption points, calculated as:

$$c_T = \sum_1^n c_i \quad (7)$$

Next, for each cell of between 2 and z the sum of distances from the cell to each point of consumption is calculated using the formula:

$$s_j = \sum_1^n dmin_{ji} * \frac{c_i}{c_M} + d_{jc} * (1 + \frac{c'_j}{c_T}) \quad (8)$$

where:

$j \in \{1, 2... z\}$, the set of cells in which we divided the geographic space in Stage 1 of the model;

d_{ji} - distance from cell *j* to consumer point *i*, $i \in \{1, 2... 100\}$, $i \in N$;

d_{ci} - distance from the central warehouse to the consumer point *i*, $i \in \{1,2,.,100\}$;

$dmin_{ji} = \min (d_{ji} , d_{ci})$;

$dmin_{ji}$ - the minimum between the distance from cell *j* to the point of consumption *i* and the distance from the central warehouse DC1 to the point of consumption *i*;

d_{jc} - the distance from cell j to the central warehouse DC1.

$$c'_j = \sum_1^p c_i \quad (9)$$

where:

$c_i \in \{1,2,....,p\}$, the set of consumer points which may be served by cell 1, that is they fulfill the condition: $dmin_{ji} = d_{ji}$;

c_T - the total demand requested in all consumer points, calculated by the formula:

$$c_T = \sum_1^n c_i \quad (10)$$

Stage IV: Determining up to *m* optimum points for placing local logistic centers.

Making use of the space division in cells from the previous stage, the iterative steps described in stage III are repeted.

The optimal location for a third warehouse is identified and this helps reduce the average delivery time to any client from the points of consumption.

Next the locations for deposits from 4 to *m* are determined.

The general algorithm is:

$S = \min \{s_1, s_2.....s_z\}$

$$s_j = \sum_1^n dmin_{ji} * \frac{c_i}{c_M} + d_{jc} * (1 + \frac{c'_j}{c_T}) \quad (11)$$

where:

j ϵ{1,2.....,z}, the set of cells in which we divided the geographic space in Stage 1 of the model;

d_{ji} - distance from cell j to consumer point i, i ϵ {1,2.....,100}, i ϵ N;

d_{ci} - distance from the central warehouse to the consumer point *i*, *i* ϵ {1,2,.,100};

d_{ki} - min (d_{D1i} , d_{D2i} , ..., d_{Dri}), where d_{Dri} = distance from the warehouse *r* to the consumer point *i*, *i* ϵ {1,2,.,100}, k is the number of deposits that have been determined so far;

$dmin_{ji}$ - min (d_{ji} , d_{ci}, d_{ki}) - the minimum between the distance from cell *j* to the point of consumption *i*, the distance from the central warehouse DC1 to the point of consumption *i* and distances from all previously determined secondary storage and consumer point *i*;

d_{jc} - the distance from cell *j* to the central warehouse;

c'_1, c_T, c_i, c_M – see Stage III for definition.

The secondary deposit D_k, k ϵ {1,2.., m} will have the coordinates for the cell that corresponds to the minimum sum (s_j = S), j ϵ {1,2.....,z}.

For each point of consumption we will determine the optimal warehouse from which the delivery will be made, that is the nearest optimal location to the point of consumption (operation which is repeated for each addition of a warehouse, changing the distribution scheme).

For each point of consumption, we will calculate the distance from the warehouse which is nearest (it was determined in Stage IV) and the delivery time, calculated using the formula:

$$T_i = d_i * v \quad (12)$$

where:

T_i - estimated delivery time from the warehouse to every point of consumption;

d_i - the distance from the nearest warehouse to the point of consumption *i;*

v - the average speed in the selected geographic region.

Stage V: Calculating the average time necessary for delivery from the central warehouse at any point of consumption

First, the sum of the length of roads which must be covered for delivery is calculated from the central warehouse to all the selected cities plus the distance to the central repository, using the formula:

$$S = \sum_{i=1}^n \max(d_i, d_i * \frac{2*p_i}{c_M}) \quad (13)$$

where:

d_i - is the length of the road from the central warehouse to the point of consumption *i;*

c_i - the demand for the consumption point I;

c_M - the average consumer demand.

Basically, the sum of distances will be composed of the lengths of roads traveled from the central warehouse to the points of consumption, taking into account at least one transport (if the consumer demand is twice smaller than the average consumer demand) or the road weighted by consumer demand (if it is higher than half the average consumer demand). It is considered that the average consumer demand requires two shipments.

The calculated amount is divided by the number of consumption points and the result is multiplied by the average speed the defined geographical region and legal average time of delivery is obtained by the formula:

$$T_m = \frac{S}{n} * v \tag{14}$$

where:

T_m - the average delivery time;
n - number of points of consumption;
S - sum of distances from a logistics center to any point of consumer;
v - the legal average speed in the specified geographical region.

Stage VI: Calculation of the average time of delivery from secondary logistic centers to any point of consumption.

For each number of optimal locations (from 2 to m) we calculate the total amount of roads covered to ensure delivery to all points of consumption, depending on the size of demand for each of them.

We must take into consideration that at each addition of a further location the scheme of distribution to the points of consumption changes (each point of consumption will be served by the nearest logistic center).

We apply steps 1 and 2 from the previous stage, calculating the average time of delivery characteristic for each number of optimal locations (from 2 to m logistic center)

We calculate the difference between the average delivery time for m locations and m-1, in order to reduce the average time of delivery to each addition of a location. The formula is:

$$\Delta t = T_m - T_{m-1} \tag{15}$$

2.3. The graphical representation of the model

For a better understanding of the way the system of delivery operates within the supply chain that can be built using the proposed model, we created figure no. 2, which is a graphical representation of a hypothetical geographic area defined by a series of consumption points, that must be characterized by their geographical coordinates and the exact size of consumer demand (for goods / services for which you want to identify optimal placement locations of logistics centers for storage facilities and / or production).

The consumption points c1, c2 ... cn represent the model input data, which are the first set on the map, and the central warehouse location DC1 and secondary deposits D2, D3, ...

D10 are output variables, namely the model results. Any point of consumption but will be served from the nearest warehouse, be it at primary (DC1) or secondary one (D2-D10).

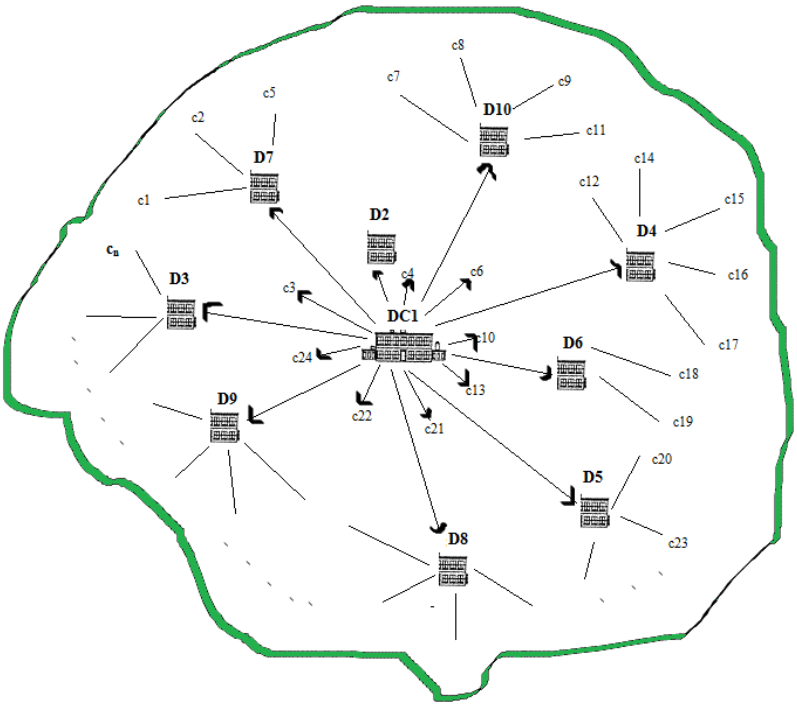

Figure no. 2: The delivery configuration for the supply chain proposed by the model in a hypothetical geographic area

The contour of the hypothetical figure delimits the geographical area chosen for the model application.

Notations:
DC1: the first optimal location identified for the entire region, which is the central logistic center (determined by the method of the center of gravity for consumption points);

D_2 – D_{10}: the optimal secondary locations identified consecutively by applying the algorithm of the model;

c_1 – c_n: the centers of consumption from 1 to *n*.

2.4. Case study

In order to validate the model, the geographic area of Romania was chosen, placing 100 points of consumption that define the space of application. The consumer points represent actual cities, defined by their exact geographic coordinates and their demand which is approximated by their population number (97% of them have over 10.000 inhabitants). For

the application of the model on the case study of Romania, we considered m=10, so a number of ten optimal locations for placing logistics centers will be identified.

The case study follows precisely the stages that have been defined in the theoretical structure of the model.

First the latitude and longitude of the cities were processed in order to be able to use them in calculations made in an excel sheet. The formula used to transform the geographic coordinates in decimal numbers is:

TEXT(ROUND(LEFT(F5,3)+(MID(F5,5,2)+RIGHT(F5,5)/60)/60,6),"00.000000") (16)

Next, the decimal numbers were synthetized in a new table (a selection can be consulted in Appendix A), based on which a chart was created to show all selected cities in form of their spatial distribution in two dimensions - latitude and longitude (figure no. 3). We mention that in order to simplify, the curvature of the geographical space, namely altitude was not taken into account.

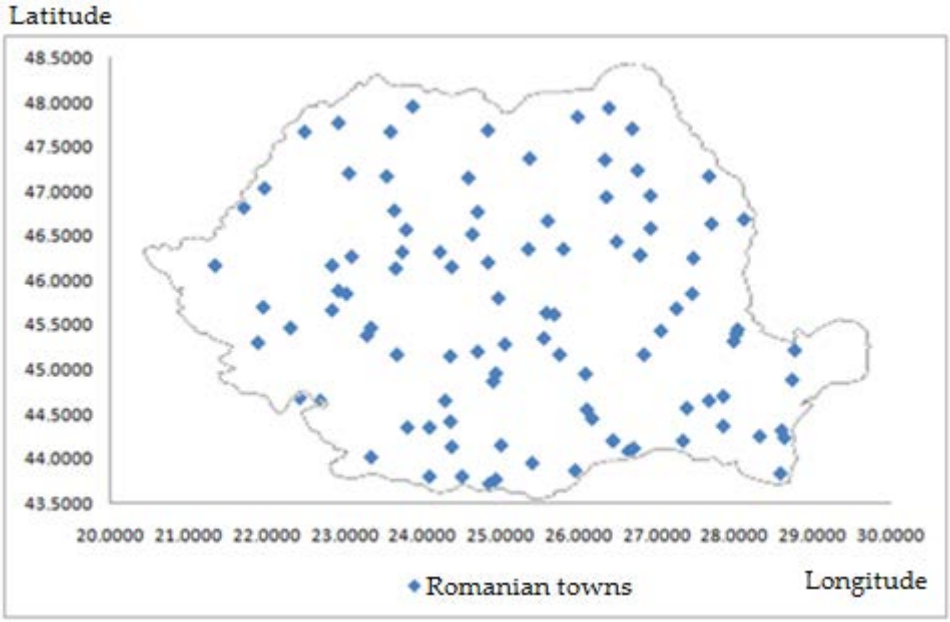

Figure no. 3: Spatial distribution of the 100 selected cities in Romania

It is considered necessary to add two hypotheses to the model, which are specific to the application of the model in the form of the case study:

- The consumption points are considered to be cities;
- The demand manifested in the points of consumption is approximated by the city's population.

For identifying the optimal location for a central repository that ensures a minimum total cost of delivery to all points of consumption, the calculations start with Stage I, defined in Section 2.2.

The first step in identifying the optimal location for a central warehouse is to determine the geographical coordinates of the center of gravity.

3. Results and discussion

As a result of calculations, the point corresponding to the computed coordinates (45.46 N, 25.63 E) was identified as the optimal location for placement of a single central repository (DC1), which ensures minimal costs for distribution of products in the 100 selected cities in Romania.

Next, the distances between DC1 and all the consumer points were calculated using the algorithm described in step 4, Stage II.

In order to identify the optimal location for the second logistic center, the first step is to divide the given geographic area in z cells as shown in the figure no. 4. Each cell is 0.01 degrees latitude and 0.01 degrees longitude, which means a width and a length equal to 0.01 * 111.1385 (number of km / degree) = 1.1113 kilometers. Hence, the surface of a cell would be approximately 1234 km^2, thus the maximum error in the application model is 1 km.

Since the map of Romania starts at a longitude of 21,5o minimum to maximum longitude 28o, and a minimum latitude 44,1o to maximum latitude of 47,4o, the total number of cells z is 214 500 according to the formula:

$$[(28 - 21,5) / 0.01] * [(47,4 - 44,1)/0,01] = 650 * 330 = 214\,500 \quad (17)$$

For cell 1 (the order is not important, it can start from any part of the map) the sum of distances from the cell to each points of consumption defined in the first stage is calculated according to the formula:

$$s_1 = \sum_1^n dmin_{1i} * \frac{c_i}{c_M} + d_{1c} * (1 + \frac{c'_1}{c_T}) \quad (18)$$

where:

$dmin_{1i}$ - min (d_{1i}, d_{ci}) the minimum between the distance from cell 1 to the point of consumption i and the distance from the central warehouse DC1 to the point of consumption i;

d_{1c} - distance from cell 1 to the central warehouse;

$c'_1 = \sum_1^p c_i$, where: $c_i \in \{1,2....,p\}$, set of the points of consumption that can be served by cell 1, and satisfy the condition: $dmin_{1i} = d_{1i.}$

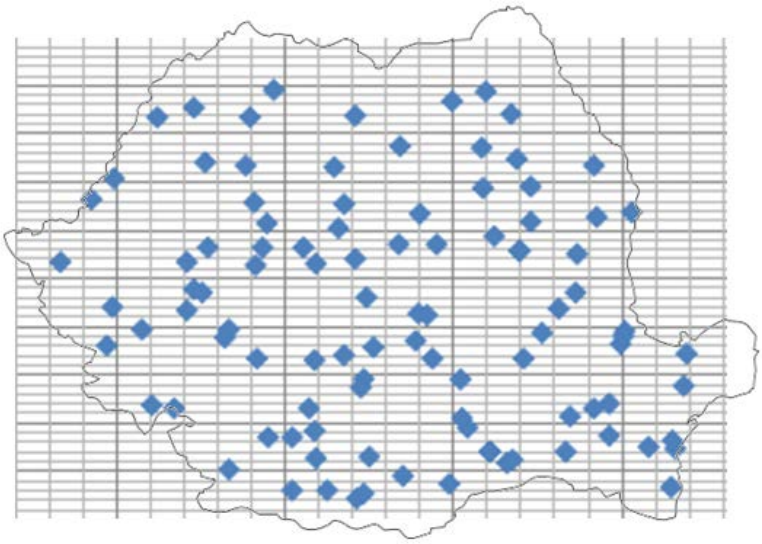

Figure no. 4: Dividing the geographic space of Romania into cells

The other variables are defined in Stage III, step 2 from the theoretical model.

Next, for each cell from 2 to n the sum of distances from the cell at each point of consumption is calculated. For each amount calculated the weighted distance from cell to the central repository identified in stage II is added (the secondary deposit must be supplied from the central warehouse). The general formula is:

$$s_j = \sum_1^n dmin_{ji} * \frac{c_i}{c_M} + d_{jc} * (1 + \frac{c'_j}{c_T}) \quad (19)$$

S = min {s_1, s_2.....s_z}; the minimum sum calculated with the previous formula was chosen and therefore was identified the cell where we must place the second point which is an optimal location for placing a secondary deposit, given the already identified center of gravity = central warehouse.

For each point of consumption, we calculate the distance from it to D2 storage and the delivery time, calculated using the formula:

$$T_i = d_i * v \quad (20)$$

By applying this algorithm in the computer programming language C + +, the result obtained was:

Optimum location 2 (D2): lat = 46.6467, long = 23.4633

Making use of the cellularisation of space method applied previously, the iterative steps in stage IV were followed. This way the optimal location for a third logistic center is identified, and so on until ten optimal locations are found consequently. Each number of

logistic centers is placed in order to insure the minimum average delivery time to any customer at one of the points of consumption.

As an additional logistic center is placed, the number of served cities for each of the optimal locations changes, as well as the total distance that needs to be covered and the average delivery time. The results for 3 logistic centers are presented in table no. 2.

Table no. 2: The results for 3 consequently determined logistic centers

Optimal location	Latitude	Longitude	Number of served cities	Population served
DC1	45.4659	25.6257	37	2 728 347
D2	46.6467	23.4633	33	2 183 393
D3	44.4467	26.1733	30	4 069 014

The total distance that should be traveled in order to reach all the consumption points is: 15525.5274 km, and the weighted total distance that will be covered in order to deliver the products to the cities, taking into consideration the population number for each, is: 29115.3158 km (for bigger cities there might be more than one transport necessary, the condition for doing more than one transport is $c_i > \frac{c_M}{2}$, as explained in Stage IV, Section 2.2).

If the objective is to to place four logistic centers in Romania, according to the placement of consumer points, the cities will be served by the nearest warehouse. The map will be divided into four zones of influence, depending on the logistic center that will serve them. Figure no. 5 illustrates how the consumer points are ascribed to the 4 logistic centers determined so far.

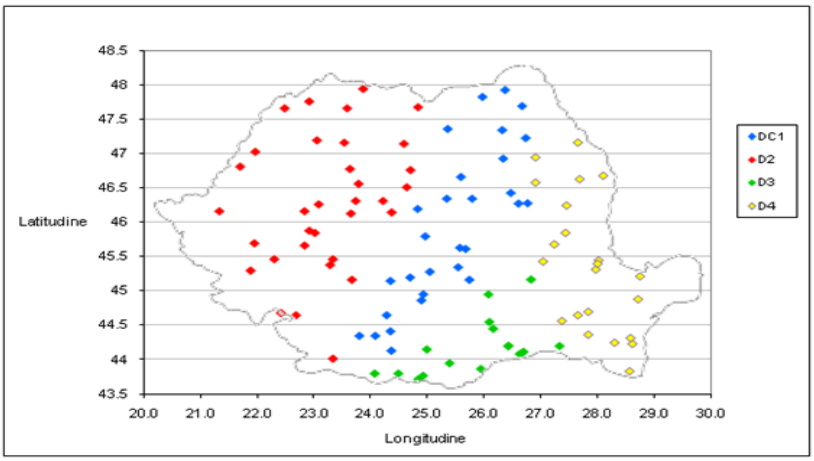

Figure no. 5: The division of cities depending of the supplying source (warehouse)

The results for each number of optimal locations between 4 and 10 are presented in Appendix B. The last iteration of the model reveals the results for ten optimal locations, placed as presented in figure no. 6.

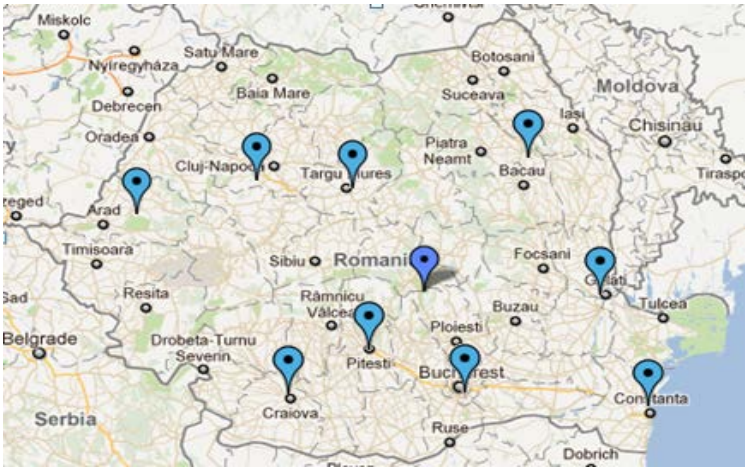

Figure no. 6: The optimal placement for ten logistics centers in Romania

Next, we proceed to Stage V, in which we calculate the average delivery time necessary for transportation from the central logistic center to all the points of consumption. After calculating the sum of all roads that need to be covered, the formula for T_m is used and the result is 6 h 55 min. We calculate the average delivery time for each number of logistic centers (from 2 to 10) using the algorithm described in Stage VI from the theoretical model presented in Section 2.2. Also of interest is the amount of time that is saved by adding a supplementary optimum location, noted with Δ t.

The results are synthesized in table no. 3.

Table no. 3: The average delivery time for 1 to 10 consecutive determined optimal locations

Number of Logistic centers	Total weighted distance (km)	Average delivery time: T_m (in hours and minutes)	Δ t (in hours and minutes)
1	48373.6462	6.9105 (6h 55m)	
2	37998.0405	5.4283 (5h 26m)	1.4822 (1h 29m)
3	29115.3158	4.1593 (4h 10m)	1.2690 (1h 16m)
4	22565.2016	3.2236 (3h 13m)	0.9357 (0h 56m)
5	19213.6671	2.7448 (2h 45m)	0.4788 (0h 29m)
6	15897.3821	2.2711 (2h 16m)	0.4738 (0h 28m)
7	14199.1577	2.0285 (2h 02m)	0.2426 (0h 15m)
8	12697.1597	1.8139 (1h 49m)	0.2146 (0h 13m)
9	11965.6024	1.7094 (1h 43m)	0.1045 (0h 06m)
10	11090.5295	1.5844 (1h 35m)	0.1250 (0h 08m)

In order to observe better the trend of decrease in the average delivery time. Figure no. 7 was built and it may be of help in the procedure of establishing the level of customer service desired.

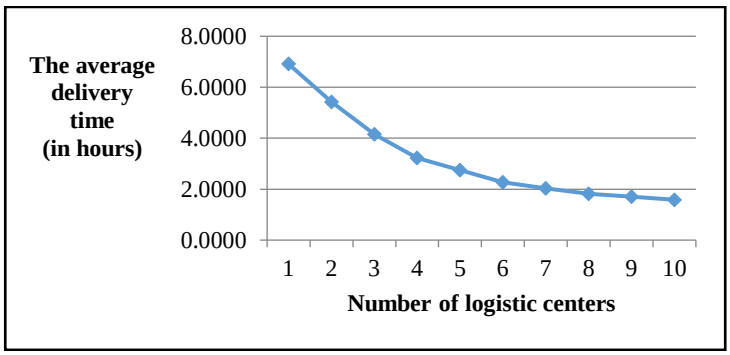

Figure no. 7: The decrease of average delivery time on adding a supplementary location

Investors which are interested in building logistic centers in our country can rely on this model to decide what number of warehouses is appropriate to have (depending on the level of customer service that they want to offer – based on the average delivery time) and where it is best to position them, in order to have a minimum cost of delivery.

Conclusions

The enunciated hypotheses have been verified by the empirical application of the model, which has been validated and proven to be functional. The model can be used as an instrument by managers or investors, in order to design the most convenient supply chain, making use of information regarding the demand and the localization of consumer points. It is also an instrument for cost minimization (for new investments or new market penetration) or expenses reduction (in case of relocations imposed by decrease of demand in certain areas). Both circumstances are characteristic to the economic situation that has been generated after the appearance of the financial crisis and that continues to cause effects on multinational companies and not only. Also, this model can be used by companies that have a green logistics strategy and want to locate their facilities in order to optimize the transportation cost, along with minimization of fuel consumption and CO_2 emissions.

Facility location decision is the critical part in strategic logistics planning. Now-a-days the location of the facilities i.e. warehouses, logistics hubs/centers etc. is the main concern of the companies related to this business (Sheikh, 2013).

The model is considered to be clearly defined by its input and output variables, as well as the stages described in more steps, so it is easy to be applied on other geographic areas, may they be economic regions, economic unions or continents. It can be also particularized for certain products, or companies, given that the specific demand can be estimated correctly. Please note that the number of consumer points that we have chosen (of 100), can also be modified without any changes in the model, as well as the maximum number of logistic centers (which was set at 10 for this case study).

As a future direction of research, reverse flows can be included in the model that we proposed. Recycling old products or parts is the next step in approaching a green logistics strategy and it is possible for reverse flows to be taken into account in the model.

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Appendix A

Table A1: The input variables of the model for the case study on Romania (selection of first 5 cities from a total of 100)

City	Longitude	Latitude	Population
Abrud	23.0833	46.3167	6803
Aiud	23.7333	46.3167	28909
Alba-Iulia	23.6500	46.1333	66369
Alexandria	25.4000	43.9500	50591
Arad	21.3333	46.1667	172827

Appendix B

Table B1: The results for placing ten logistic centers in Romania

Optimal Location	Latitude	Longitude	Number of served cities	Number of served population
DC1	45.4659	25.6257	6	444 873
D2	46.6467	23.4633	16	1 116 966
D3	44.4467	26.1733	11	2 731 976
D4	45.4467	27.9833	10	888 670
D5	46.8667	26.9733	15	1 198 212
D6	44.3567	23.8033	12	676 892
D7	46.2967	21.8033	6	559 115
D8	44.2367	28.6833	6	470 905
D9	44.8667	24.9033	8	470 046
D10	46.5167	24.6333	10	423 099