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Location of Production Facilities in the Framework of Sustainable Development

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Abstract

Sustainable development is a necessity, solutions for satisfying users' needs having to be adopted in relation to criteria that often integrate divergent interests of those involved. The optimal location of production centers has the best effect on production costs. The paper focuses on industrial location from the user's point of view, taking into account elements like maximum distance for efficient road transportation, resources proximity and available infrastructure. The developed model has a large scale of applicability in economic sectors like: distribution, automotive industry, constructions. Results of applying this model proved its utility and necessity of further researches on location problems.

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Keywords: Facility location; optimization; logistics; simulation.

1. Introduction

Location theory has evolved from classical, descriptive models to mathematical, deterministic and probabilistic models. Starting from the studies of the XVIIIth century when Turgo established the principles of commercial location theory, continuing with VonThunen at the beginning of the XIXth century that explained the land rate maximization location theory and Weber that in 1909 elaborated the first industrial location model that had as a goal the minimization of the transport costs, location theory has been constantly evolving till now when the recent

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location - allocation models developed were integrated within Geographical Information Systems, by generating the data in GIS format and by enclosing the objective functions of different models [1].

Macroeconomic tendencies' study, with impact on transport and logistics organizations, is the starting point of the decision of studying this subject (Table 1).

Table 1. Transport and logistics activities' evolution for representative economic sectors

Economic sector	Market evolution	Transport modes evolution	Location and logistic services
Distribution	Annual growth 5%	Strong dependency on intermodal transfer installations	Stock level reducing and cross-docking development Information system for goods tracking Logistics operations externalization Increased demand for logistic platforms Number of proximity stores increase
Construction materials industry	Annual growth from 5 to 7% Production centers development (especially Asia) on a growing market (location of production facilities close to raw materials extraction points) and the number of consumption centers increase	Railway transportation usage where the services are regular and safe	Location is done close to ports/quarries/plants (raw materials and parts)

*Source: SESP, 2007 [2]

Production facility location is often limited to the area of raw materials extraction, small plants satisfying the local demand and coexisting with large producers for the global supply. Construction materials plants are mainly supplied with raw materials straight from quarries and their distribution is achieved by rail, road and naval transportation, with an accent on road transportation as production and consumption are seasonable and trip length is relatively short. So, this activity sector needs a soft (relatively short distances), adaptable (as it is seasonable) and reliable (from the time point of view) transport system [3]

Producers' decisions with influence on transport operations are placed on three levels:

- strategic, regarding number, location and capacity of plants, warehouses, stores and terminals;
- tactical, following production and distribution timing by establishing discrete goods flows' size;
- operational, trying to manage the transport resources (transport mode, vehicles, routes and loading usage).

Goods transport increase led to a complex interaction of the three levels of decision. Strategic decisions influence the transport flow - weighted length (tonns·km) opposite to the tactical and operational ones that influence the traffic flow (vehicles·km).

Opposite to industry and agriculture that within the production process transform objects of labor in new products, transportation does not bring up any new product as it consists in raw materials and products transport with one main characteristic - it is not stock able [4].

Freight movement needs (for supply, distribution, construction, etc.) and people's need for mobility (work, education, fun and shopping), determining the so called transport demand, characterized by relation (origin-destination), size and structure are directly connected to land use decisions [5]. Finding and selecting the best locations of production units is a challenge for actors in the field and the solutions used by policy makers could be generated by the use of the so-called location-allocation models.

Location-allocation models select the optimal locations from a set of possible locations in the most efficient manner and allocate demands for a particular kind of service to these locations, according to the distribution of demands [6]. The location of different types of facilities and allocation of the demand to those locations was implemented in GIS software (Geographic Information System). The main objective of location models is to ensure covering all demands from a certain area within a predefined path length or in a predefined standard response time.

The conducted study uses location-tracking models and GIS functions for the existing distribution of chalkstone extraction centers and for the cement and concrete production centers to see if all the demands are met or if new production centers are needed and where to locate them. The study thus has two major objectives:

- determination, based on existing production centers, of the demand service mode (for a predefined distance) and the associated costs.
- determining the positions of new production centers leading to increased service accessibility and costs reduction.

This research consists of a systematic study of the existing variants of location-allocation models by comparing their results and applying them to identical data sets regarding the construction materials industry in our country.

2. The mathematical model - a case study

After thorough study of the location models and of various distribution schemes developed at local, regional, national and even international levels the necessity to develop a location model on two levels (producers of raw materials and intermediate products necessary in achieving other finished products and finished products for which there is a considerable demand) arisen. This model can have a wide application and can be adapted to the requirements of economic sectors as diverse as great distribution, automotive, construction materials etc.

By choosing construction materials industry, developing economic sector even in times of crisis (because of the need for new infrastructure), as a recipient of the model realized we tried that besides the economic benefits brought to a certain area and the resident population, known a priori (development of infrastructure, jobs, economic growth), to highlight the effects on transportation processes brought by establishing a new industrial facility which, in a based on production economy, would have scale effects on the economy [7].

The model is shown schematically in Figure 1, each of the two levels consisting from raw material producers, industrial chalkstone quarries and cement factories, respectively, cement factories and concrete plants and is similar to an intermediate centers transport problems [8]. Between each of these levels there are flows of goods on relations possible to be determined.

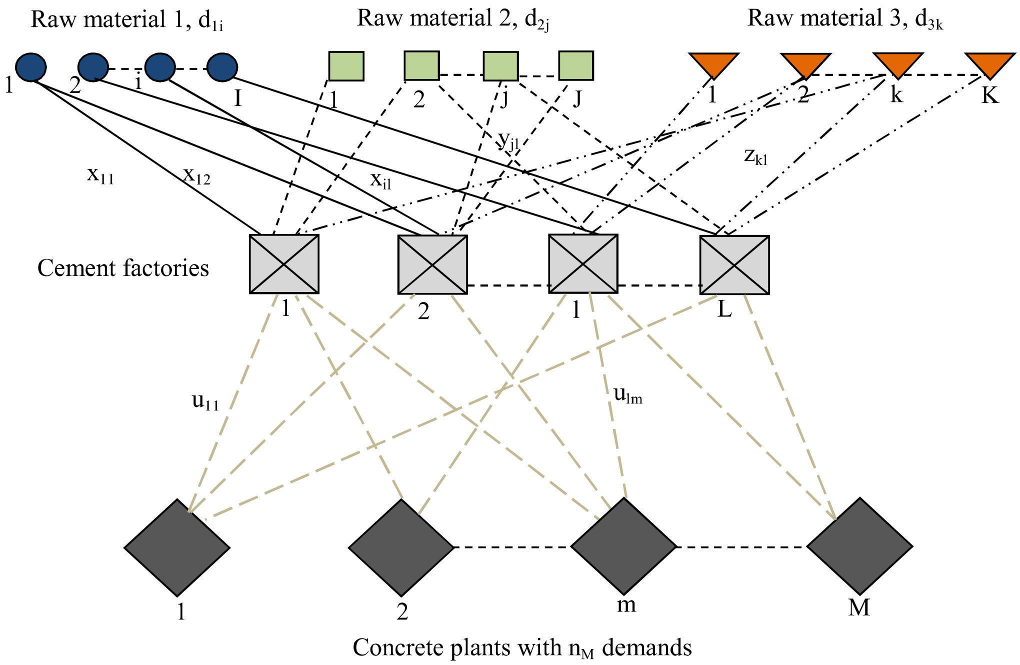


Fig. 1. Schematic representation of the proposed mathematical model

The objective function of the model can be written as:

$$\min \sum_{i=1}^{I}\sum_{l=1}^{L} x_{il}c_{il} + \sum_{j=1}^{J}\sum_{l=1}^{L} y_{jl}c_{jl} + \sum_{k=1}^{K}\sum_{l=1}^{L} z_{kl}c_{kl} + \sum_{l=1}^{L}\sum_{m=1}^{M} u_{lm}c_{lm} \tag{1}$$

with restrictions:

$$x_{il} \geq 0, y_{jl} \geq 0, z_{kl} \geq 0, u_{lm} \geq 0, \ \forall \mathrm{i} \in \mathrm{I}, \forall \mathrm{j} \in \mathrm{J}, \forall \mathrm{k} \in \mathrm{K}, \forall l \in \mathrm{L}, \forall \mathrm{m} \in \mathrm{M} \tag{2}$$

$$\sum_{l=1}^{L} x_{il} \leq d_{1i}, \sum_{j=1}^{L} y_{jl} < d_{2j}, \sum_{l=1}^{L} z_{kl} \leq d_{3k}, \ \forall \mathrm{i} \in \mathrm{I}, \forall \mathrm{j} \in \mathrm{J}, \forall \mathrm{k} \in \mathrm{K} \tag{3}$$

$$\sum_{i=1}^{I} x_{il} = 1/\alpha_2 \sum_{j=1}^{J} y_{jl} = 1/\alpha_3 \sum_{k=1}^{K} z_{kl}, \ \forall l \in L \tag{4}$$

$$\sum_{m=1}^{M} u_{lm} = \sum_{i=1}^{I} x_{il} + \sum_{j=1}^{J} y_{jl} + \sum_{k=1}^{K} z_{kl} = \sum_{i=1}^{I} x_{il}(1+\alpha_1+\alpha_2) \tag{5}$$

$$\sum_{l=1}^{L} u_{lm} = n_m, \ \forall m \in M \tag{6}$$

The objective function minimizes the sum of transport costs from production points of raw materials to cement factories and transport costs from cement factories to concrete plants. Restriction 2 shows the existence of raw materials. Restriction 3 requires that the availability of every raw material is enough to serve the demand for any raw material. Restriction 4 shows the proportion of each raw material in the production of cement recipe. Restriction 5 is a flow conservation restriction and restriction 6 imposes necessary cement for the production of concrete [9,10].

This problem can be solved by separating the levels listed. Therefore, two transport problems with related production centers, where the first problem regarding the proper transport of raw materials could be solved by addressing three programming problems for the three types of raw materials (Figure 2).

The second problem has to ensure that the necessary quantities are provided by the existing or new factories located, provided that:

$$\sum_{l=1}^{k} \partial_l = \sum_{l=1}^{L}\sum_{m=1}^{M} u_{lm} = \sum_{m=1}^{M} n_m \tag{7}$$

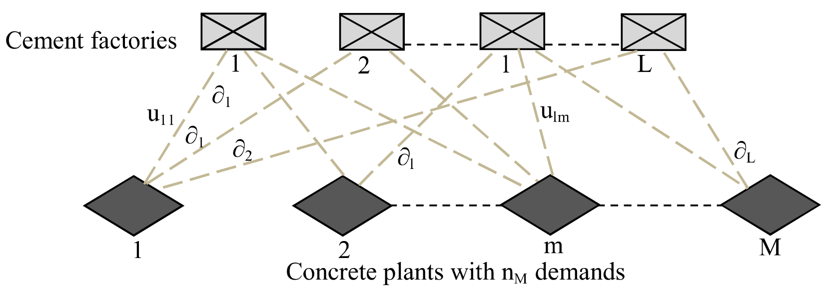


Fig. 2. Representation of the problem with two components

Possible new locations of cement plants, represented by the existing cement terminals, together with the other locations in the issue, are the summarized in Figure 3 [12,13].

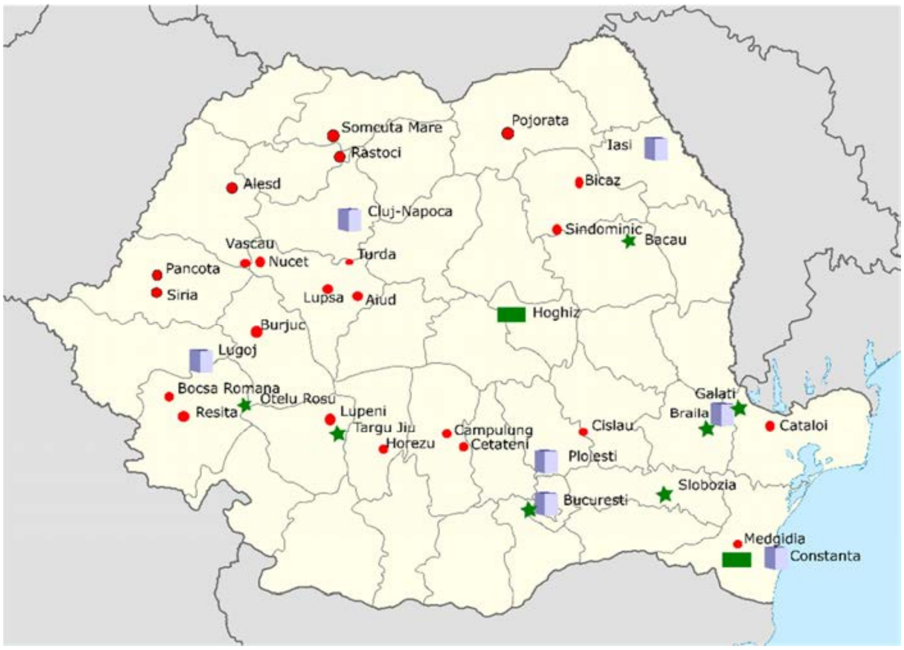


Fig. 3. Chalkstone quarries, cement factories, cement terminals and concrete plants locations in ArcGIS

Next, we defined the layers with the data necessary to analyze the location-allocation models (hierarchy levels for the considered centers: chalkstone quarries, cement plants and concrete plants, Figure 4).

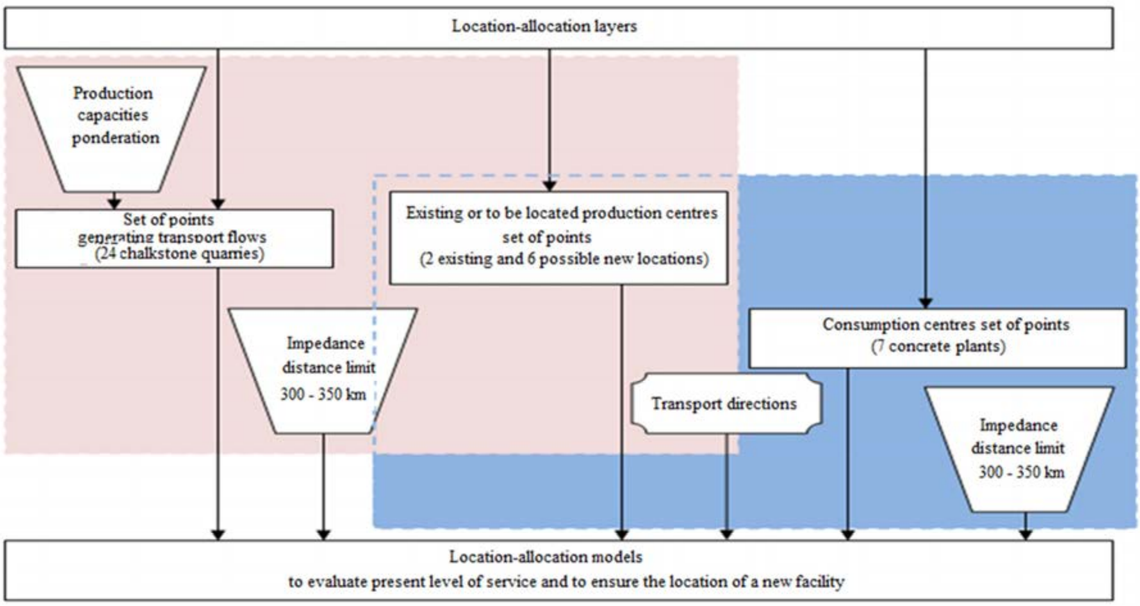
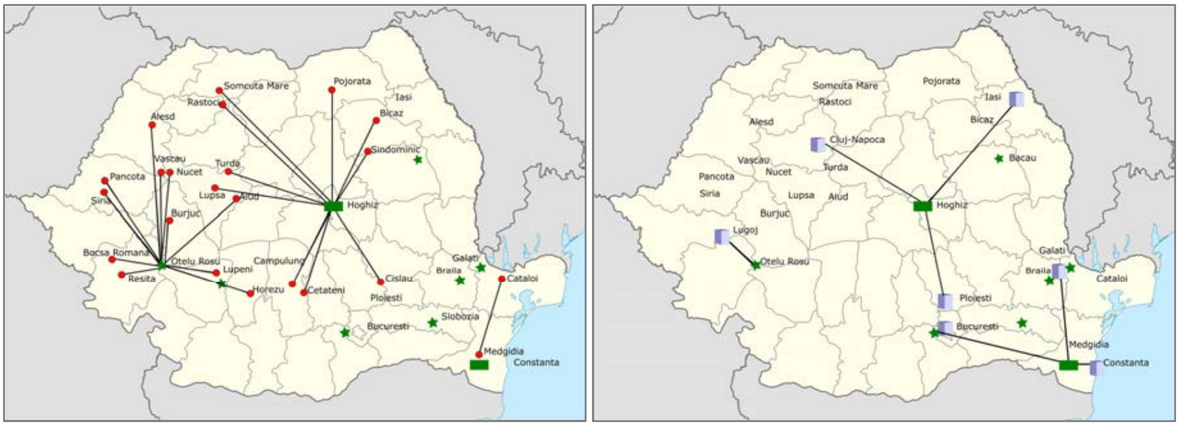


Fig. 4. Block diagram for location modeling procedures

The first step is to define location-allocation layers with Network Analyst tools and afterwards the positions of existing production centers (cement factories) that were added and those in which it is possible to make further locations (terminals). Raw material supply points (chalkstone quarries) were in turn placed on the network and have been considered to be transport flows' generators. Then, weights were associated based on the production capacities. Later, a limit impedance distance (300-350 km) was established and the direction of travel was requested from the feedstock supply point to the cement factory (Figure 4). Similarly, based on the corresponding cement factories and concrete plant the second level of the problem was built for the situation where cement factories serve the concrete plants.

Assessing the limit impedance distance to 350 km and requiring choosing a location for a new cement factory, among the cement terminals already located on the network, the obtained results are shown in Figure 5.a.



a b

Fig. 5. a) The allocation of chalkstone quarries to cement factories - 350 km distance limit impedance, with a new factory located.
b) The allocation of the cement factories to concrete plants - 350 km distance limit impedance, with a new factory.

Due to the impossibility of covering all demands using the limit impedance distance of 300 km (or even the 350 km one) emerged the need to verify the opportunity of using a new cement factory with the location determined in the previous level of the problem. The results are shown in Figure 5.b.

As can be seen from the simulations carried out, in the existing situation the cement factories cannot ensure an efficient operation of service vehicles, transport distances exceeding the limit of 300-350 km for which road transportation is effective both for the chalkstone quarries - cement factories situation and for the cement factories - concrete plants one. Calculation of transport indicators (Table 2) highlighted these issues and allowed the search for a solution to create a new production center among the existing cement terminals. It was identified as an appropriate location of a new cement plant in Otelu Rosu, establishment that can benefit both the upstream situation and the downstream one.

In the initial situation by establishing the limit impedance distance of 300 km, a total of 10 chalkstone quarries extraction capabilities were underused or unused (Pancota, Siria, Nucet, Alesd, Vascau, Bocsa, Lupeni, Somcuta and Pojorâta) and a concrete plant may not be provided with the necessary raw material (cement), Lugoj.

For the level of chalkstone quarries - cement factories case by placing a new cement factory a reduction with 43% of the total annual useful service was achieved which led to a reduction in annual transportation costs by about 37%. For the downstream situation, cement factories - concrete plants it determined an annual reduction of useful service of 34% and a reduction of the annual transportation costs by about 27%.

Table 2. Transport indicators

		Transport indicators		
		Annual total distance covered [km/year]	Annual useful service [loaded vehicles.km/year]	Annual transportation costs [EUR/year]
Level of location	Chalkstone quarries - cement factories	42369600	868096800	50843520
	Cement factories - concrete plants	24950400	1172899200	29940480
	Existing aggregated model chalkstone quarries - cement factories - concrete plants	67320000	2040996000	80784000
	Chalkstone quarries - cement factories	26633280	488911200	31959936
	Cement factories - concrete plants	18130560	763708800	21756672
	New aggregated model chalkstone quarries - cement factories - concrete plants	44763840 -33%	1252620000 -38%	53716608 -33%

The aggregated model chalkstone quarries - cement factories - concrete plants has led to an annual useful service reduction of 38% and a reduction of annual transportation costs by approximately 33%. By creating a new cement factory a reduction of the transportation costs can be observed (by 33% for the aggregated model) and also, a better demand service for raw materials (Figure 6).

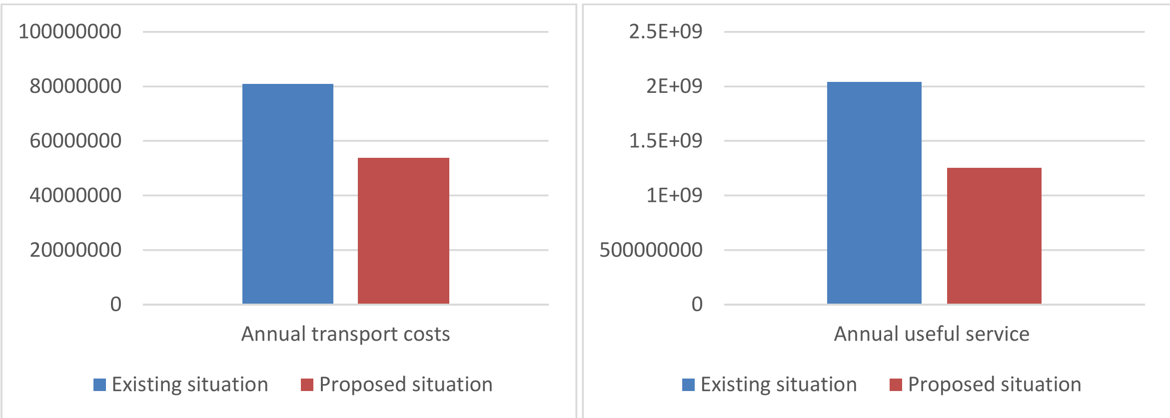


Fig. 6. Comparison of the transport indicators for the aggregated model chalkstone quarries - cement factories - concrete plants for the existing situation and for the one where a new cement factory is located

To achieve a new cement factory with an annual production capacity of 1 million tons the investment value rises up to approximately 300 million EURO [11]. Based on the equivalent cost indicator we can say that in a period of approximately 12 years the investment costs will pay off, so that in addition to social benefits (such as the creation of new jobs) such investment would bring financial benefits in a relatively short time horizon.

3. Conclusions

To recognize the need of activities' location and/or relocation actions the material flows they would generate must be a priori known, meaning the products that will materialize in transport (raw materials and finished products), together with the set of points of production units already placed and their potential sites.

The model developed aggregates three levels of production (quarries, cement factories and concrete plants) so, as the number of origin/destination points is quite high, a deterministic model is difficult to solve. It was developed a simulation model with variables like demand for raw materials, the area covered by production centers and their capacity.

The model's logic scheme was developed and led to the determination of the position of a new production facility after the GIS data integration. Evaluating the existing situation led to the conclusion that none of the existing levels of problem is efficiently satisfied by establishing a limit impedance distance of 300 km. So, first, the location of a new cement factory was determined in relation to the location and capacity of the chalkstone quarries and, subsequently, this new opened location has been used to assess transport indicators relative to concrete plants.

Comparison of the transport indicators shows that locating of a new production center leads to a reduced total distance traveled by beneficiaries of the system created, which draws a decrease in transportation costs, energy consumption and polluting emissions and also positive social effects (jobs, infrastructure, etc.). Equivalent costs indicator allows the assessment of the financial efficiency of the investment, observing that in a relatively short period (10-15 years) reduced transport costs could lead to the return of the investment realized for the development of a new production facility.

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