Application Of Some Locational Models in Natural Resources Industry - Agriculture Case

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Abstract

Nowadays large scale, uncertainty and multiple objectives appear increasingly in decision processes. One of the very important strategic decision for starting a business is where to locate facility. Application of operations research methods and models has had a great success throughout the years, including modeling and solving various location problems. Natural resources industry, especially agriculture sector, is a significant factor of growth and prosperity most commonly for developing countries. Operations research/management science (OR/MS) contributions in each one of applied areas of natural resource industry – agriculture, fisheries, forestry and mining are very significant. In this paper we present application of Capacitated Facility Location Problem (CFLP) in agriculture sector and we are encouraging researchers to use quantitative techniques in order to manage the use of different natural resources.

Keywords: Natural resources industry, Agriculture sector, Location analysis, Capacitated FLP

1. Introduction

By using natural resources according to their needs, a man survived and evolved as a cultural, social and spiritual being. The development of various technologies shaped the life of modern man, but led to the rapid exploitation of its environment, and the rapid depletion of resources. People have changed the face of the earth more than any other species in the history of the planet - and the speed of these changes is increasing. People today spend between one-third and one-half of what the global ecosystem created.

The natural resources of a country determine its wealth and status in the world economic system, its power and political influence. According to this, it is obvious that operations research, as a discipline that deals with the application of advanced analytical methods to help make better decisions has a significant impact on decisions in this area. Application of operational research methods and models to modelling of complex realities and development of algorithms for problems increasingly difficult to solve has had a great success throughout the years (Weintraub, 2007).

Operations research has played an important role in the analysis and decision making of natural resources, specifically, in agriculture, fisheries, forestry and mining, in the last 40 years (Weintraub, 2007). There are natural differences related to the form of managing the production in each application. For example, the time horizons of growth and extraction vary from months to a year for fisheries and agriculture, to almost a century for some tree species. Mining is non-renewable, and, as such, is associated with a different type of natural resource (Bjørndal et al., 2012). Mine lives can run for a few years to centuries. In agriculture, farmers are primarily concerned with how to plant crops and raise animals more efficiently.

Decisions in forestry are centered around the strategic, tactical and operational levels of managing plantations and public lands to meet demands while adhering to supply restrictions, which are coupled with events such as forest fires and policies, e.g., environmental regulations and concerns (Bjørndal, 2012).

Operations research, e.g. location analysis has been applied to handle various problems in agriculture and forestry area, elaborating on mathematical techniques and successful applications. In this paper we present one more application of OR/MS in agriculture sector and we are encouraging researchers to use quantitative techniques in order to manage the use of different natural resources efficiently from an economic as well as an environmental point of view.

2. Natural Resources Industry and Or/Ms

According to the significance of natural resources especially today, it would be expected that operations research (OR) could have made a significant contribution to decision making in this area. But achievements in practice have been disappointingly small. The industry comprises of a large number of small individual businesses which do not permit specialisation in management functions. Consequently, technical advice and much R and D is provided from public funds. OR applications for agriculture have mainly been developed by Universities, Colleges, State Advisory Services and Quangos. Quango is a quasi-autonomous non-governmental organisation is an organisation to which a government has devolved power. In the United Kingdom this term covers different “arm’s-length” government bodies, including “non-departmental public bodies", non-ministerial departments, and executive agencies. The Forestry Commission, which is a non-ministerial government department responsible for forestry in England and Scotland, is an example of a quango (Wikipedia, http://en.wikipedia.org/wiki/Quango).

Some techniques are frequently used in agriculture like linear programming, dynamic programming and simulation. Other techniques have had limited uptake and application. Reasons for the pretty low impact of OR are outlined as a set of problems specific to farmers and their systems and problems specific to computer use. One of the obvious problems in efficient application of OR/MS methods and techniques are in recruiting and training OR specialists for these specific fields of application. Generally, how important OR models are in decision making depends on several factors (Weintraub & Romero 2006):

- The quality of data,
- The competitiveness of markets,
- Ownership and
- The culture of the application area and peoples' understanding of OR's advantages.

There exists several ways for increasing OR impact in these areas: one is in training today's farmers (and, probably more important, future farmers) in an understanding of what computers can do and what models are available. There is a general lack of good flexible formulation of problems to be dealt with by OR techniques. A third problem is the need for much more efficient two-way communication and feedback between the developers of OR tools for agriculture and practical farmers. At present OR has connotations of being of little use to practical farmers, but of great value to academic enthusiasts who are unable and/or unwilling to transfer ideas into practicality.

3. Application of location models in agriculture sector

Location theory has found its use in agriculture since the early days of the field. The theory of spatial equilibrium and optimal location and the foundations of agricultural location theory are traced back to the classical work of von Thunen in 1826. He investigated the impact of the distance from the market on the use of agricultural land.

In agriculture, use of OR models is increasing with advances in hardware and software. The most commonly used OR techniques are LP models, simulation, risk programming, and multiple-criteria programming. People use models at two levels and for two purposes. They use them to improve decisions at the farm level, and they use them to help policy makers predict the impact of policy changes on farmers' behaviour (Weintraub & Romero 2006). Lucas and Chhajed (2004) give an overview of application of location analysis in field of agriculture and some selected applications of location analysis in agriculture are presented in table 1.

Selected applications of location analysis in agriculture (adapted from Lucas and Chhajed (2004))

Table no. 1

Authors	Problem description	Features
Grain storage in South Brazil (Borstein and de Casto Villela, 1990)	Optimal location of warehouses for grain storage, then location of service stations for technical assistance	Economies of scale Political, economic, and social aspects Partially funded by State Agency
Soybean-processing industry (D. Souza, 1988)	Optimal number, size, and location of soybean processing plants	Large size, with 57 regions US Economies of scale Multi-commodity (soybeans, then meal and oil) Consideration of two base periods 1977-1981 and predictions for 1999 and 2000
Cattle-slaughtering industry in Queensland, Australia (Brown and Drynan, 1986)	Selection of plant sites, sizes, throughputs and product flow	Economies of scale Marked seasonal and year-to-year variations Comparison of results form static and dynamic models
Post-harvest handling-chain operations in Northern Tahiland (Chu, 1989)	Optimal number and location of cooling facilities and assignment of production sites to those facilities	Large-size problem with 30 villages and 50 kinds of vegetable products, Problem decomposition, based on access road network and on locations of various extension stations Seasonality of production volumes and access road conditions Project supported by Government
Dairy industry in Ontario, Canada (Polley, 1994)	Changes in existing network (closing of several plants and warehouses) at Aults Foods – Canada's largest diary processor	Analyse the benefits of specializing each plants production mix and using multiple sources for shipping depots Sensitivity analysis with sales projection for 3, 5 and 10 year 30 plant production strategies
Brewing industry in Turkey (Koksalan, 1995)	Optimal locations of new breweries, and optimal distribution plans for malt and beer	Large-scale problem with 15 alternative cites and 300 customer zones High seasonality of beer demand, capacity constraints

Mladenović (2004) states common classification of location problems into (a) continual, (b) discrete, and (c) network models. Location problems in agriculture exhibit several features, such as their large scope and size, or the consideration of multiple and often conflicting objectives and, thus, demonstrate increased levels of complexity and realism. Common in agriculture are location– allocation problems, in which the number of facilities, their locations, and these interactions all become decision variables. Moreover, these location–allocation problems themselves are often complicated by routing decisions, leading to location–allocation-routing models.

Lucas and Chhajed (2004) presents six groups of location analysis application in agriculture: a cotton-ginning problem, the location of grain subterminals, the collection and processing of rubber, the fresh citrus packing industry, the cattle-slaughtering industry and The Bangladesh grain model. These applications of location analysis in agriculture do not consider solving of airfield location problems. Description and solution of one of the first problems regarding location models in agriculture aviation in Serbia can be found in Andrić Gušavac et al. 2013.

3.1 Simple and capacitated plant location problems

The simple plant-location problem (SPLP), also known as the uncapacitated facility-location problem, is one of the fundamental and most studied models in facility-location theory. The objective is to choose, from a set of potential facility-locations on a network, which ones to open to minimize the sum of opening (or fixed) costs and service (or variable) costs to satisfy the known demands from a set of customers. Although the origins of the plant-location problem go back to the pioneering work of Weber (1909), the actual of SPLP may be attributed to Stollsteimer (1963), Kuehn and Hamburger (1963), and Balinski (1965). In view of the size of facility-location problems that being tackled in practice today, ability to solve very large SPLPs is becoming more important. Mladenovic et al. (2006) develop a new methodology for solving the SPLP using variable neighbourhood search (VNS) to obtain a near-optimal solution, and they show that VNS with decomposition is a very powerful technique for large-scale problems, up to 15,000 facilities × 15000 users. Hansen et al. (2007) emphasized the fact that the SPLP is finding other applications in such areas as cluster analysis, computer and telecommunications network design, information retrieval, and data mining.

A basic CFLP model was formulated by Balinski (1961) and Manne (1964) for the simple plant location problem. This problem consists of locating plants and warehouses among a set of given locations in order to satisfy a given demand at minimum cost.

The assumption that all potential sites equally costly used like in maximal covering location problem, *p*-center, *p*-median problems, and location set covering problem is dropped in the simple plant location problem and its variant, the capacitated plant location problem (CPLP). Its objective is to locate an unspecified number of facilities and to meet all demand while minimizing the sum of site-related and transportation costs. The model makes a number of assumptions, the most important of which are as follows (Eiselt & Sandbloom, 2004):

- The facility can be supplied with unlimited resources whose prices do not vary by source;
- The transportation costs from factories to markets are linear, i.e., there are no economies of scale;
- The production costs at a facility are linear in a quantity produces once an initial fixed cost has been incurred;
- Demand in known and does not vary with changes in the delivered price;
- There is no capacity limitation on the quantity produced at a factory (for the SPLP);
- There is a fixed cost for purchasing and developing a site of selected for a facility.

Given the above assumptions we can define the following parameters. Denote by the fixed costs for opening facility , is the distribution cost for satisfying demand of user from facility . Then we need to define two sets of variables: is a binary variable equal to 1 if facility is in use and 0 otherwise; variable is the percentage of a satisfied demand of a user from facility . Now we can formulate the simple plant location problem as follows.

$$\min_{x,y} z_p = \sum_{i=1}^{m} f_i y_i + \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} x_{ij} \qquad (1)$$

s.t.

$$\sum_{i=1}^{m} x_{ij} = 1, \quad \forall j \in I \qquad (2)$$

$$x_{ij} - y_i \le 0, \quad \forall i \in I, \forall j \in J \qquad (3)$$

$$y_i \in \{0,1\}, \quad \forall i \in I \qquad (4)$$

$$x_{ij} \ge 0, \quad \forall i \in I,\ \forall j \in J \qquad (5)$$

The placement of upper limits (that is, capacities) on supplies transforms an uncapacitated problem into a capacitated one. The CFLP is defined by introducing another type of constraints (6), which refers to the capacity of airfields. Denote by surface of fields in hectares and capacity of each airfield. Capacity of airfields is defined as total amount of fields in hectares which can be cultivated from every airfield.

$$\sum_{j=1}^{m} d_j x_{ij} \le Q_i y_i, \quad \forall i \in I \tag{6}$$

CFLP has wide application for analysis of single-commodity location problems where capacity is an important consideration--that is, where management wishes to place a cap on the maximum output for any one facility.

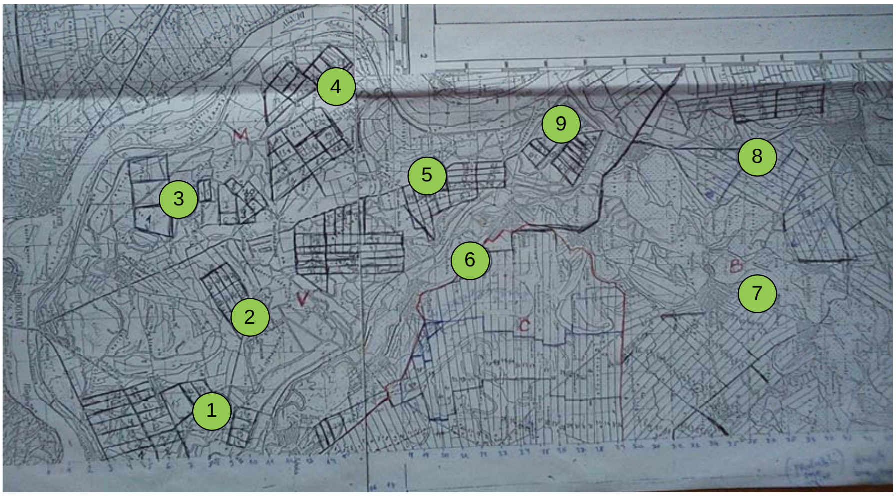
4. Case Study: Agriculture

Simple plant location model is applied on large agriculture filed of company X which is situated near Belgrade (Andrić Gušavac et al. 2013). Company X is one of the leading companies in food production and production of this corporation is main base for meat and milk industry, industrial and other vegetables used in food industry. This company is considered as the premier supporter of the stable supply of high quality forage, fresh produce and dairy products to the local and regional markets. They own nine large agriculture fields with different crops: wheat, barley, corn seed, corn mercantile, soy etc. They use land mechanization and agriculture aviation for nutrition and protection of agricultural crops. This spring they processed 15000 ha of arable land with land mechanization and two aircrafts. Underground water represents great problem and limiting factor for successful fulfilment of agro technical deadlines. These deadlines are especially important in corn production, since corn is cultivated on 62.72% sawn area. Use of aircrafts in the technology of growing these crops would give better results in terms of yield and quality and also it will be necessary to use aircrafts due to underground water. (Jakovljević, 2006)

Subject of location models application is one of nine agriculture fields with approximately 9000 ha which is divided into 245 small fields and one part of land is unusable. Map of this part of land is presented in Figure 1. This part of land has nine airfields. Company had a problem to determine which of the airfields to activate, and how to allocate 245 fields to specific airfields. Each airfield is represented by a green node.

Map of arable land divided into fields

Figure 1



Source: *(Andrić Gušavac et al. 2013)*

Two groups of costs are summed up in the objective function (1). The first group represents the sum of costs f_i for opening airfield i, security and maintenance of that airfield. The second group of costs includes distribution costs c_{ij} for satisfying the demand of field j from airfield i, and these costs are proportional to distance between center of fields and airfields. In order to equalize units of two groups of variables in objective functions, model requires the conversion of the distances to distribution costs with unitary distribution cost of 1 EUR/km.

Distances between center of these fields (which have been earlier calculated) and airfields were calculated using Euclidean metric, where one distance unit represents 0,5 kilometers. Euclidean metric was used due to rectilinear aircraft movement.

The Euclidean distance between points p and q (7) is the length of the line segment connecting them (). If $p = (p_1, p_2,..., p_n)$ and $q = (q_1, q_2,..., q_n)$ are two points in Euclidean n-space, then the distance from p to q, or from q to p is given by:

$$d(p,q) = d(q,p) = \sqrt{(q_1 - p_1)^2 + (q_2 - p_2)^2 + \cdots + (q_n - p_n)^2} \quad (7)$$

Capacity of airfields is defined as total amount of fields in hectares which can be cultivated from every airfield. Capacity for each airfield is presented in table 1.

Capacity of airfields

Table no. 2

Airfield	1	2	3	4	5	6	7	8	9
Capacity [ha*100]	10	10	10	10	10	25	25	10	10

There is a slight difference between capacities of airfields. Airfields 6 and 7 were built as the first airfields in this area. These airfields were supposed to cultivate all of the arable land, and accordingly to this, the capacity of the chemical and gasoline storage were quite large. In the following period, it was obvious that these two airfields could not fulfil all of the needs of the arable fields. This resulted in setting up new lesser capacity airfields. Airfield area is calculated with the Heron's formula.

Fixed costs for each airfield

Table no. 3

Airfield	1	2	3	4	5	6	7	8	9
Fixed cost	70	70	70	70	70	100	100	70	70

Fixed costs are the same for each airfield – this is the case because all the airfields approximately are of the same size and capacity with same costs for opening – therefore the costs are the equal. Differences between these costs occur only for airfields 6 and 7 as a result of larger capacity.
Distribution costs between center of one example field (field 1) and every airfield are presented in table 2. Demand of each field refers to its surface in hectares (for example surface of the first airfield is 0,21ha^2).

Distribution cost between center of field 1 and airfields

Table no. 4

Airfield	1	2	3	4	5	6	7	8	9
Field 1	3,07472	4,34427	7,69806	9,86206	7,93396	6,27875	12,11549	13,63764	10,57403

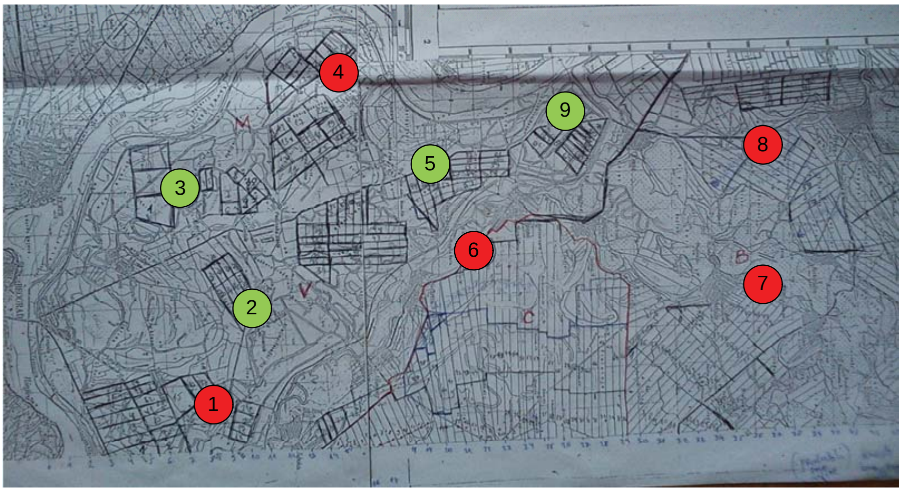
The model was solved using GLPK software package. This package (GNU Linear Programming Kit) is intended for solving large-scale linear programming (LP), mixed integer programming (MIP), and other related problems. The GLPK package consists of several main components, including stand-alone LP/MIP solver - glpsol. The model was solved in order to suggest which airfields should be activated and used for cultivation. The solution also gives allocation of every field to specific airfield. Solution file from the solver has comprehensive insight in all the elements of the model solution:

1 objective: Total costs (=1093.17096)
2459 constraints:
Coverage
Allocation
Capacity
2214 integer variables
5 active airfields (1, 4, 6, 7, 8)

Solution of the problem is presented in figure 2. Red nodes represent chosen airfields. Fields allocated to the specific airfield are situated mainly around airfields. Most of the fields are allocated to airfield number 6, which is central airfield in the cultivation area. This is not a surprise: most of the fields are located in that area. Allocated fields are not graphically presented on the map, but could be presented in direct contact with authors. Within the limits of the experiments conducted in this real world and agriculture planning context, it is shown that this model is applicable to this type of problem. Of course, additional factors can be included when solving this type of problem.

Map with chosen airfields

Figure 2



The number of fields allocated to the specific airfield is presented in the figure 3. Red nodes represent the activated airfields. This problem was firstly solved as a simple plant location problem, but there exist several factors which were not taken into consideration. One of these factors is a capacity of each airfield – defined as a total amount of hectares which can be cultivated from each airfield in a given period of time. This requires calculation of surface of each field in order to include this factor into model. Two solutions of the analyzed problem are presented in figure 3. Solution of the problem when simple plant location model is applied and the solution when a capacitated facility location problem is applied are presented in figure 3.

Solution of the problem - application of SPLP and CFLP

Figure 3

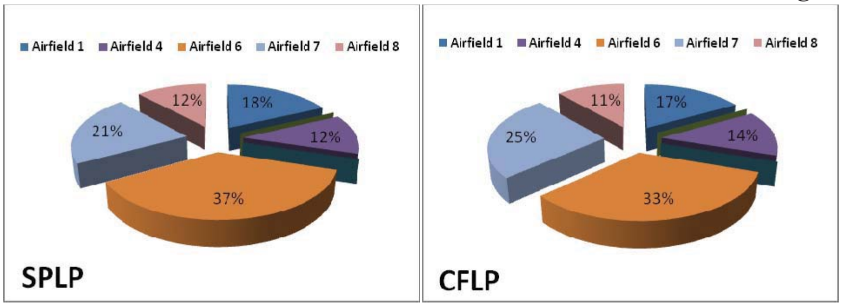


Figure 3 presents procentige of all fields which are cultivated from each activated airfield. There is a slight difference between result of SPLP and CFLP application which occurs as a result of a limited capacity of the airfields, but in the both cases the same airfields should be activated.

Capacity utilization of airfields

Table no. 5

Airfield	Maximum capacity of airfields [ha*100]	Capacity utilization [ha*100]
1	10	9.81110
4	10	9.39511
6	25	24.90626
7	25	19.96847
8	10	9.98313

Previous table shows a remarkable capacity utilization of airfield 1 (98%), airfield 4 (94%), airfield 6 (99%), airfield 7 (80%) and airfield 8 (99%).

Application of this solution enables the company to maximize use of capacities of the airfields. The remaining airfields can be closed and that area can be turned into arable land.

5. Future research

Application of a location model helps the management to orient their decision for airfields location rapidly and easily. Authors are convinced that a simple tool helps decision making and that the management should include the modeling results in business analysis including their possible preferences, so as to bridge the gap between measurability optimality and unpredictable and immeasurable compromises. Several more criteria should be taken into consideration for choosing airfield location, for example, proximity to the central airfield (main) or proximity to the important roads, etc. The results of this research could serve as an initial base for future optimization in agriculture aviation, where solutions could increase productivity and decrease energy supplying.

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